Proton Improvement Plan
PIP

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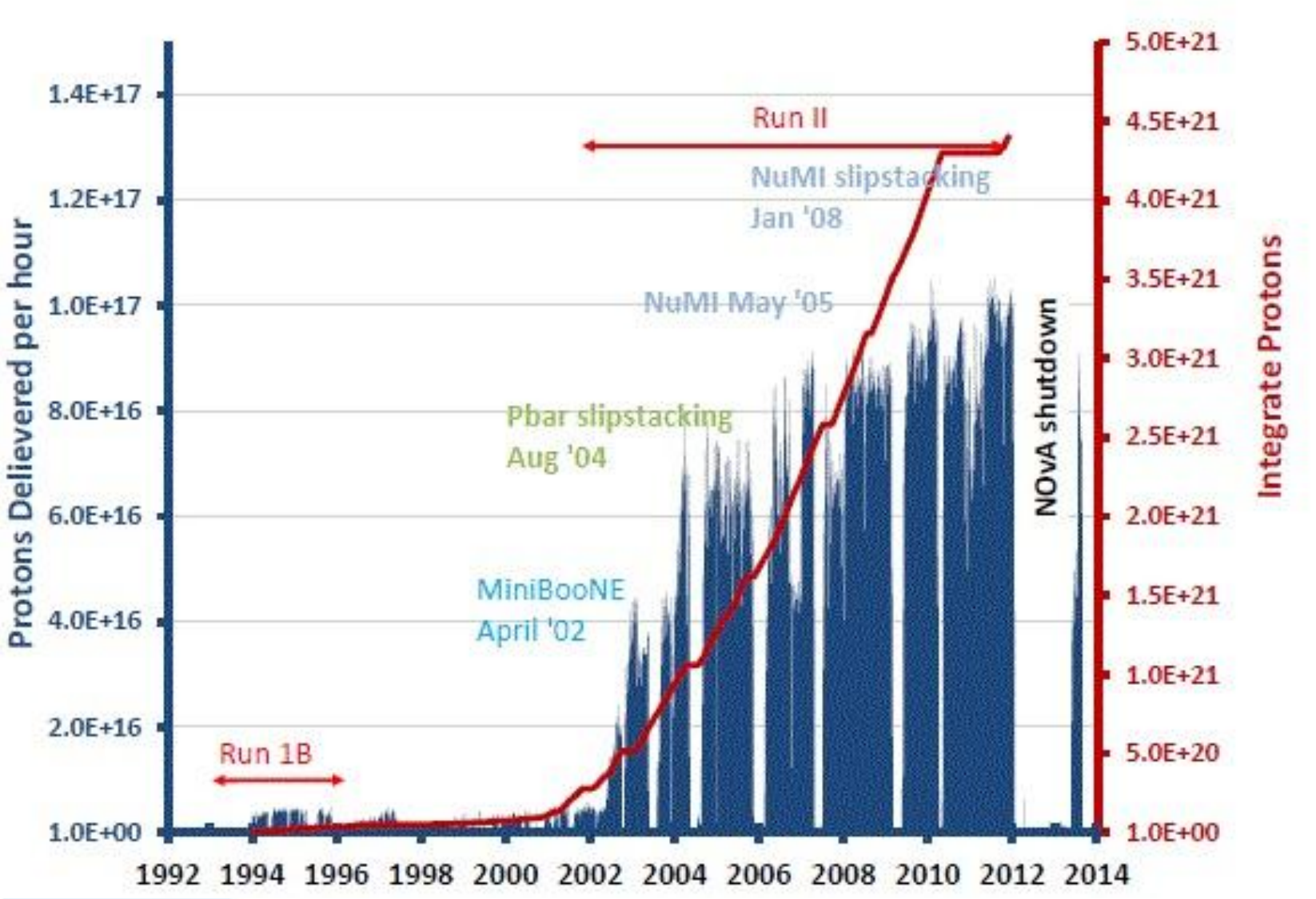
U.S. DEPARTMENT OF ENERGY | Office of Science

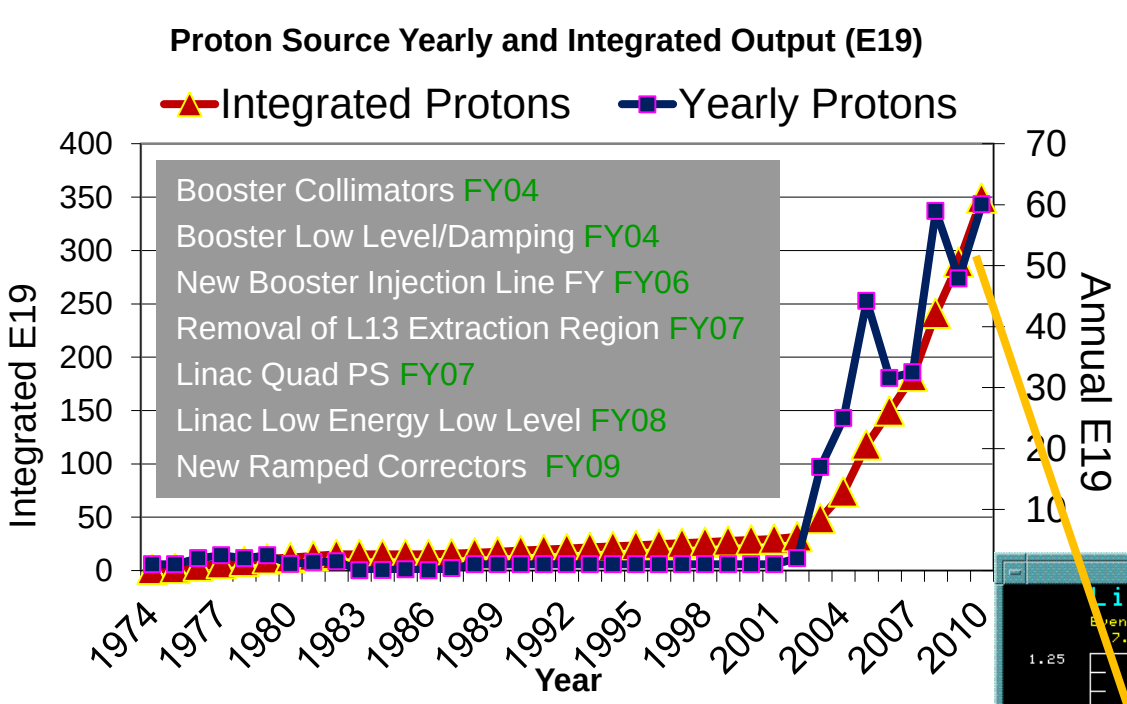
Fermilab

Outline

- This talk will focus on Proton Improvement Plan's (PIP) recent work and management. Historical reference will be given to help give perspective of where we were and where we are going.
- Initialization
  - Why do we need PIP
  - Goals
- First two years
- Present Effort
- Plans
- Management and Controls
  - PIP structure
  - PIP controls
  - PIP planning

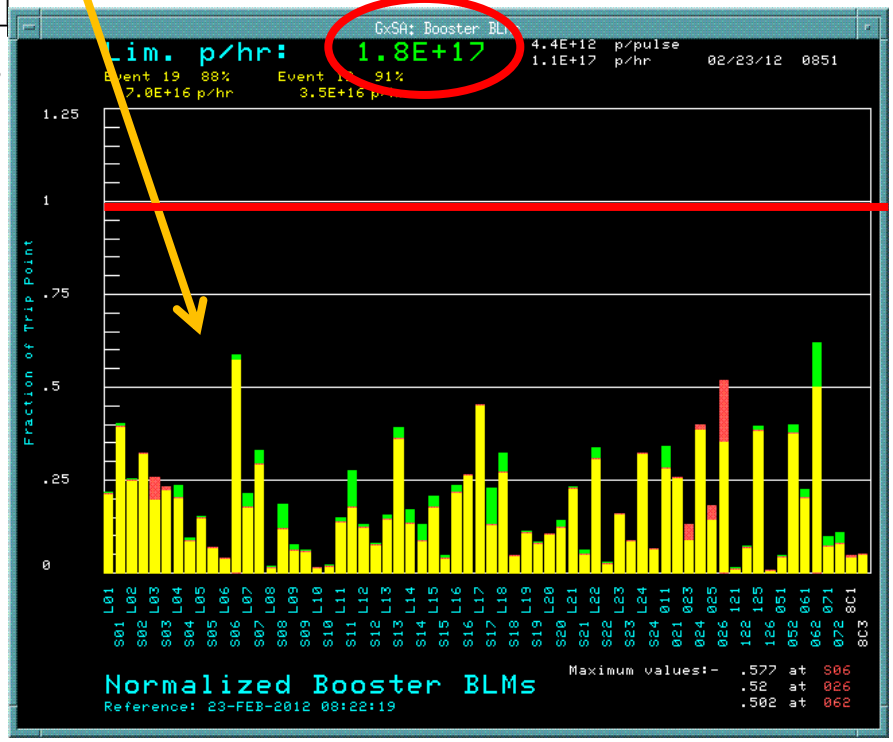
Proton Source Historic Proton Flux





Beam loss limits were set at levels with personnel safety (ALARA) first – flux output increases came with efficiency….

(from ~68% to over 90%)



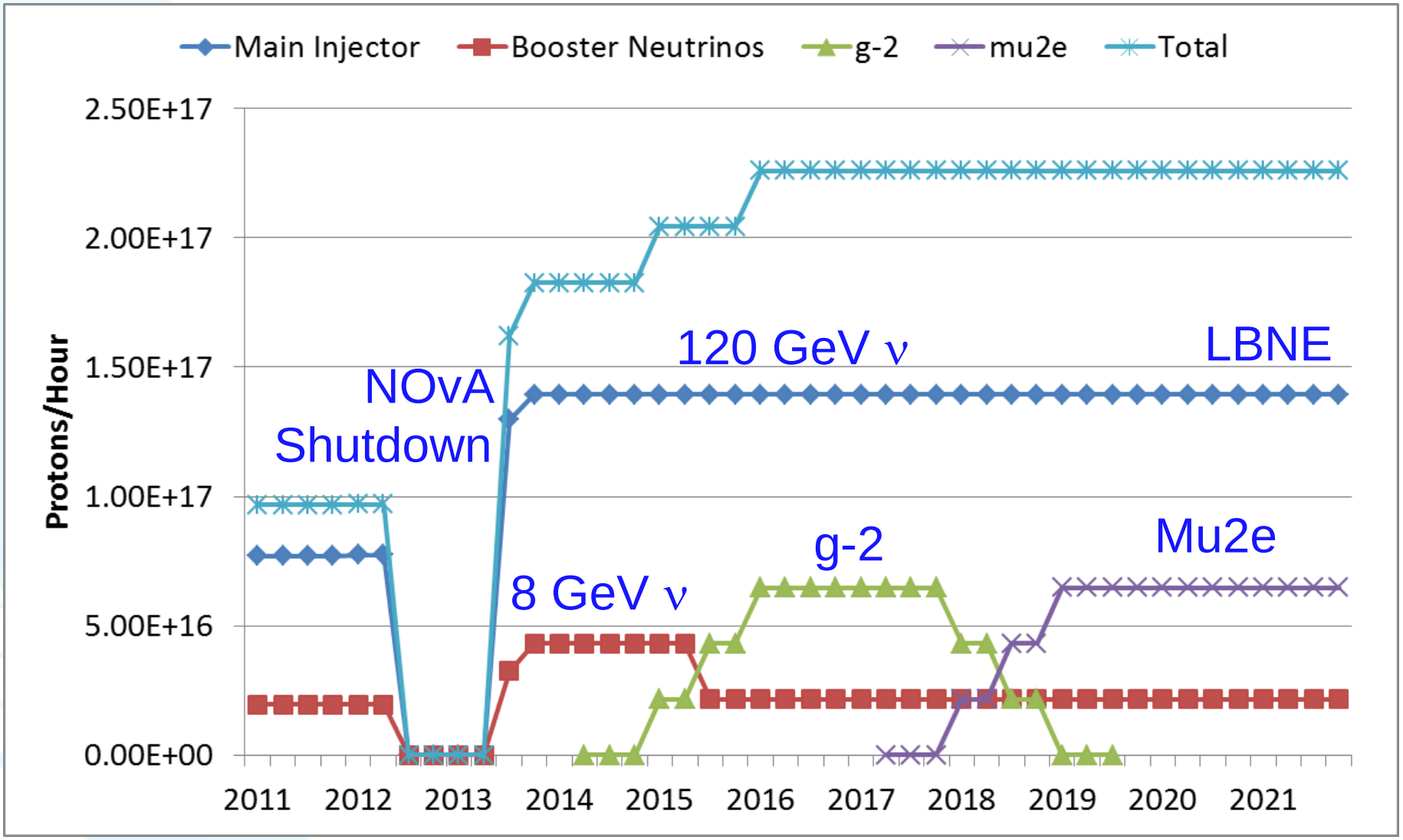
A ten-fold increase in hourly rates, lower loses and higher uptime.

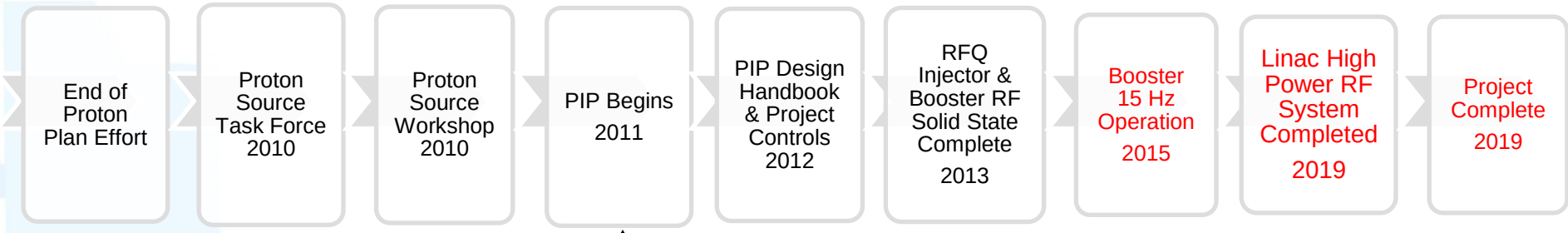
The flux ramp-up for the intensity frontier took time, money and labor….

Almost 8 years of effort before the PS was able to exceed beam requests.

Requested Proton Flux

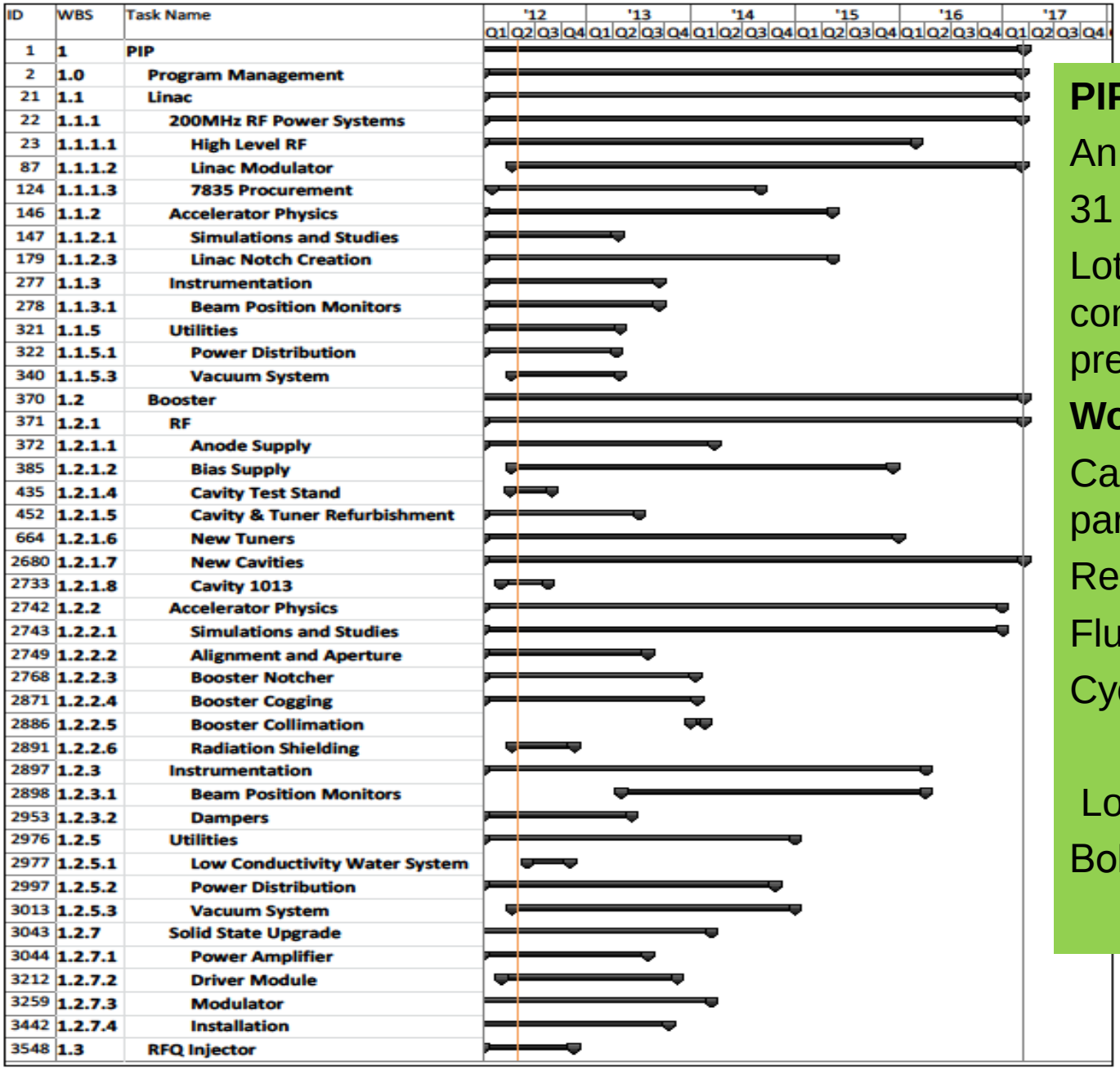
Adjusting to program planning





S. Henderson (and DOE)

- If we make a commitment to the physics program, we must deliver on that commitment
- Conversely, we should not make plans for the experimental program if they're not supported by plans for delivering the beam
- Failure to deliver on today's programmatic commitments jeopardizes tomorrow's plans
- This planning process serves very important functions of 1) developing a path to achieve the program goals we have already signed up for, 2) providing a basis for realistic planning going forward
- Therefore
  - I view the completion of the PIP, and our execution of it as an urgent, extremely high-priority activity
  - I have made the completion of the PIP a priority for AD management
  - I will commit to working at the Directorate level to funding a plan of reasonable scope.



ID	WBS	Task Name
1	1	PIP
2	1.0	Program Management
21	1.1	Linac
22	1.1.1	200MHz RF Power Systems
23	1.1.1.1	High Level RF
87	1.1.1.2	Linac Modulator
124	1.1.1.3	7835 Procurement
146	1.1.2	Accelerator Physics
147	1.1.2.1	Simulations and Studies
179	1.1.2.3	Linac Notch Creation
277	1.1.3	Instrumentation
278	1.1.3.1	Beam Position Monitors
321	1.1.5	Utilities
322	1.1.5.1	Power Distribution
340	1.1.5.3	Vacuum System
370	1.2	Booster
371	1.2.1	RF
372	1.2.1.1	Anode Supply
385	1.2.1.2	Bias Supply
435	1.2.1.4	Cavity Test Stand
452	1.2.1.5	Cavity & Tuner Refurbishment
664	1.2.1.6	New Tuners
2680	1.2.1.7	New Cavities
2733	1.2.1.8	Cavity 1013
2742	1.2.2	Accelerator Physics
2743	1.2.2.1	Simulations and Studies
2749	1.2.2.2	Alignment and Aperture
2768	1.2.2.3	Booster Notcher
2871	1.2.2.4	Booster Cogging
2886	1.2.2.5	Booster Collimation
2891	1.2.2.6	Radiation Shielding
2897	1.2.3	Instrumentation
2898	1.2.3.1	Beam Position Monitors
2953	1.2.3.2	Dampers
2976	1.2.5	Utilities
2977	1.2.5.1	Low Conductivity Water System
2997	1.2.5.2	Power Distribution
3013	1.2.5.3	Vacuum System
3043	1.2.7	Solid State Upgrade
3044	1.2.7.1	Power Amplifier
3212	1.2.7.2	Driver Module
3259	1.2.7.3	Modulator
3442	1.2.7.4	Installation
3548	1.3	RFQ Injector

PIP – Original schedule

An aggressive 5 year plan

31 initial level 4 projects

Lots of documentation, controls, meetings and presentations

Work –

Can be divided into 3 parts:

Reliability/Viability

Flux

Cycle Repetition Rate

Lots has changed

Bob will give details ….

RFQ Injector Line (RIL)

First PIP task to be completed: FY12

In house expertise: Ion Sources, RFQs, novel chopping, LE beam dynamics & compact beam elements

Effort to reduce high extractor spark rates:

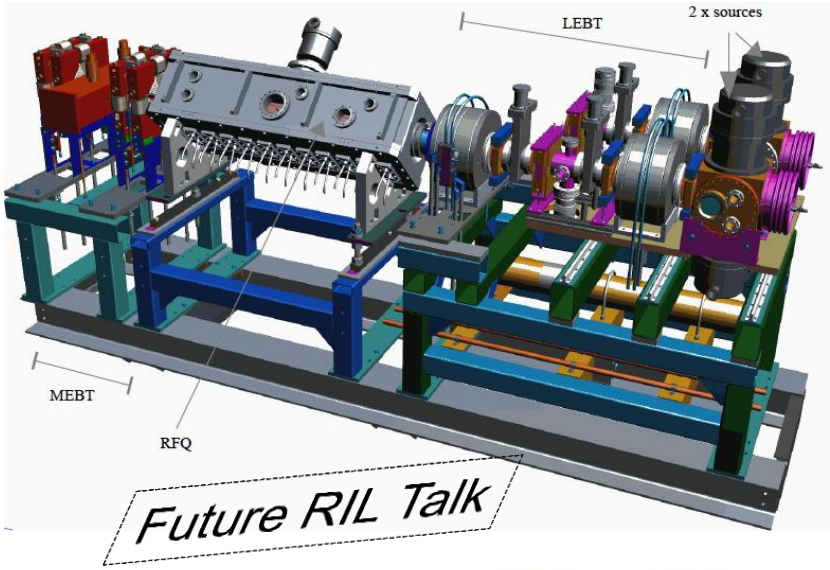
- Improved materials (molybdenum inner anode cover plates, tungsten extractor cone tips, titanium outer anode cover plate)
- New magnets and Yoke
- Better understanding of Cs flow rates
  - Monitoring of source body and Cs tube temperatures

Operations:

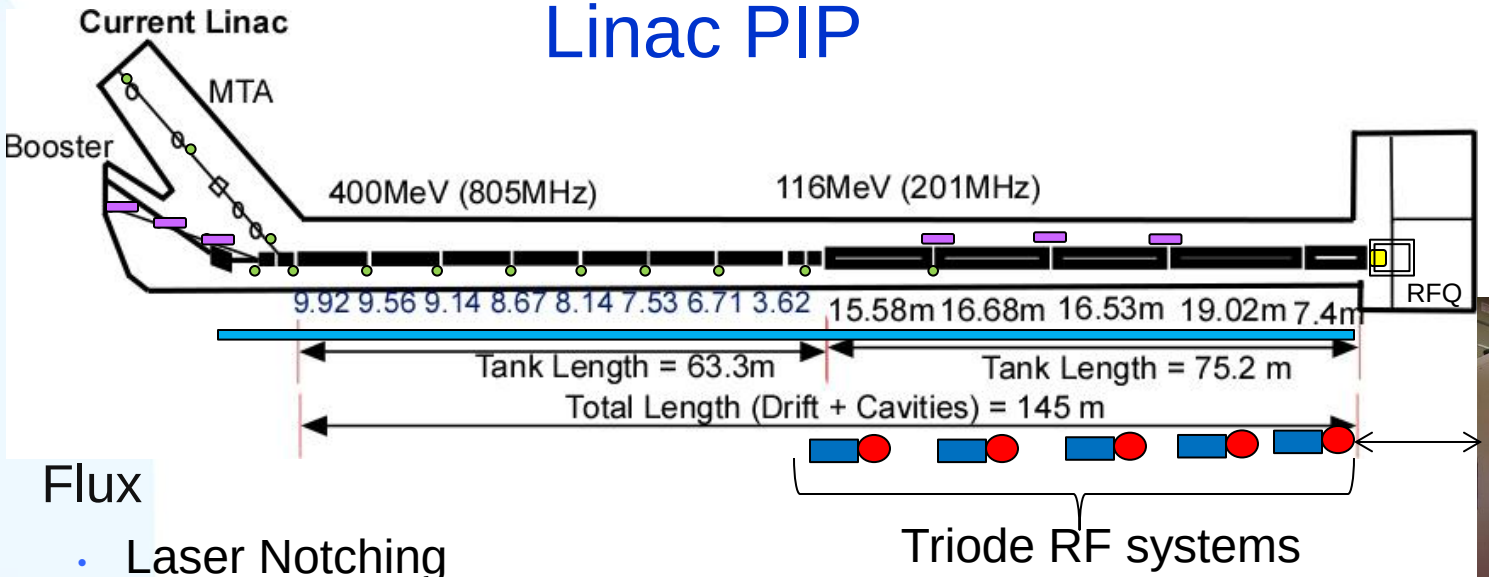
- We have swapped sources 3 times
  - with practice could be <20min
- Adjusting tuning parameters

Ongoing projects:

- Gas valve replacement
- 2 stage extraction
- DTI extractor pulsers
- Fiber optic links to HV rack
- Spectrometer looking at Cs to H ratio
- Cs handling (change boiler to accept Cs without ampule)
- Better heaters (right now the heaters are too interactive)
- Current regulated arc modulator
- Optical spectrometer installed for Cs monitoring in the plasma. Will be operational soon.



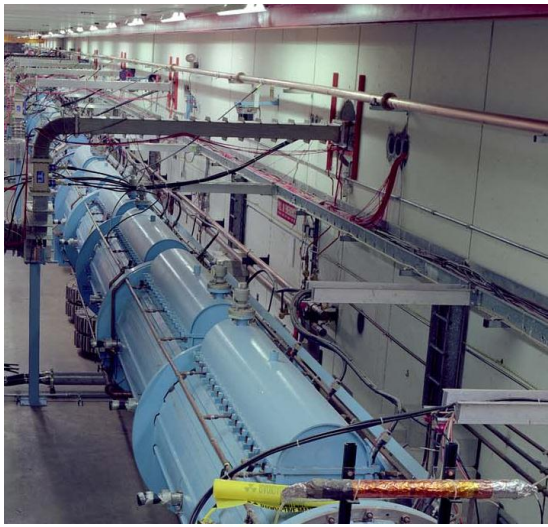
Linac PIP



Modulator &
7835 Tube Socket

- Flux
  - Laser Notching
  - Beam Physics
  - Upgraded diagnostics/software
    - BPMs
    - Toroids
- Vulnerability
  - Modulators, Driver Solid State RF source
  - Burle 7835 tube system
  - Utilities
    - Vacuum (Roughing stations, pumps, valves…)
    - LCW (pumps, plumbing)
    - Power (transformers, MCC, breakers, distribution)

Low Energy Linac



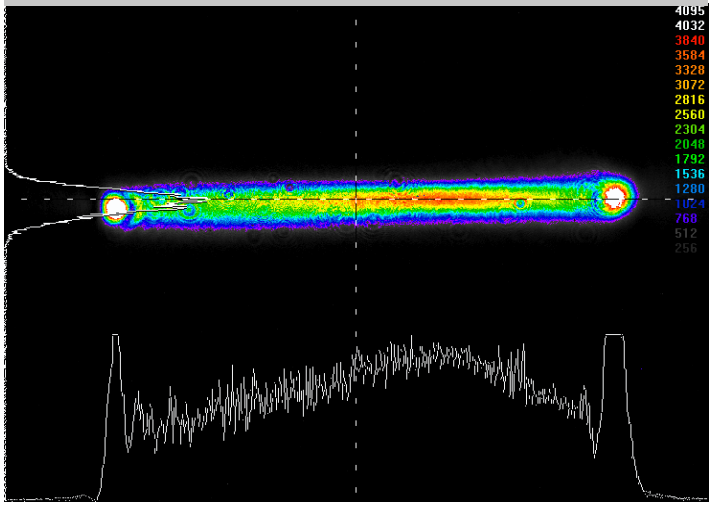
Laser Notching (After RFQ – 750 KeV)

Progressing in a Pre-Acc notching

- Working of timing electronics
- Vacuum chamber complete
- Final assembly – FY14 Q1

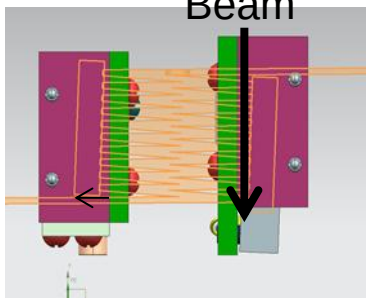
Upcoming talk D. Johnson

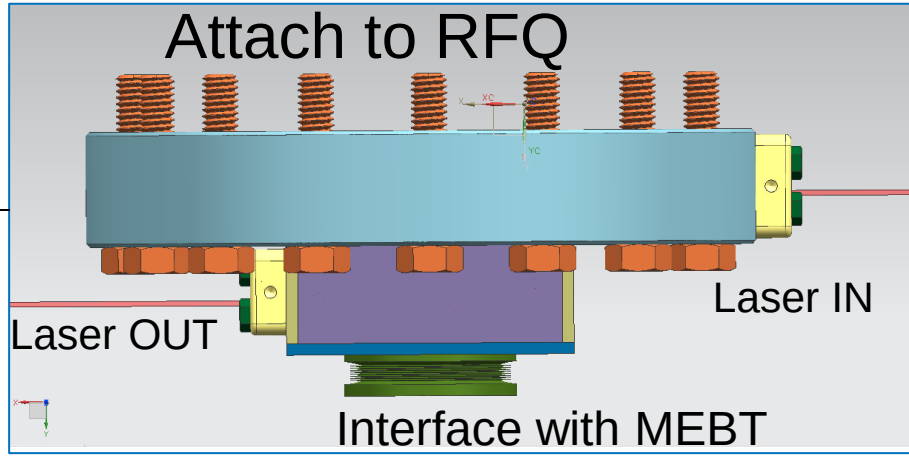
Testing of beam shaping optics



200 MHz pulses

450 kHz





Linac Beam Physics

Goals: To obtain accurate on line Linac model from RFQ injector to Booster injection (foils).

Generate beam envelope (Twiss-Parm) - emittance and efficiency

TRACEWIN, TOUTATIS, PARMILA, PARMTEQM and MAD

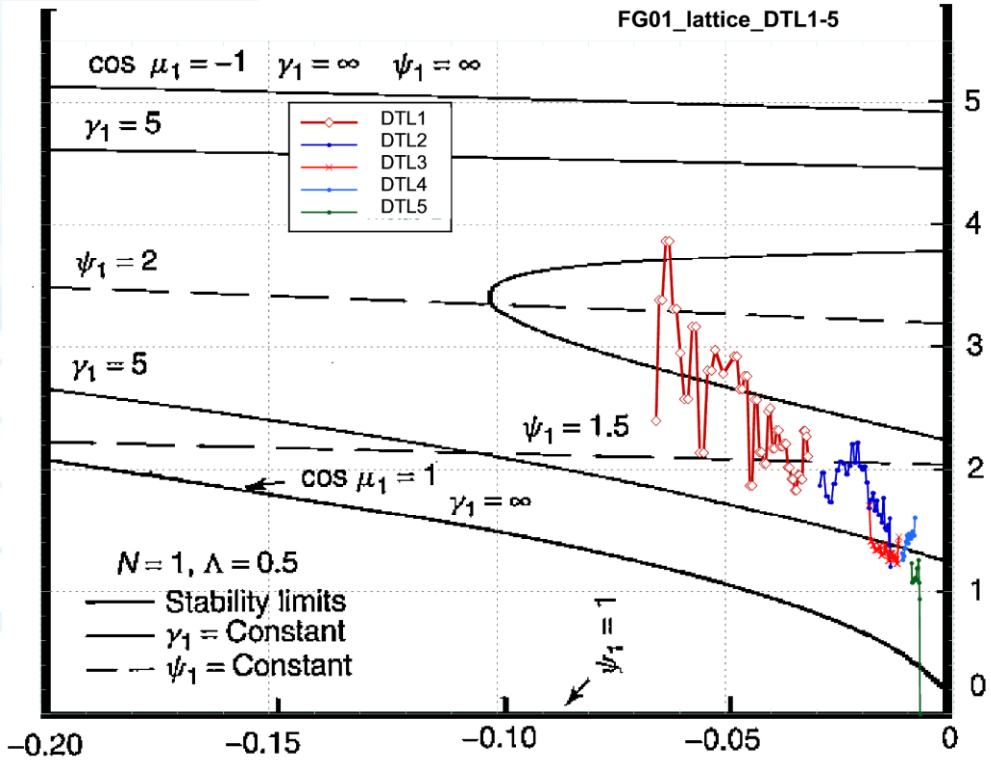
Optimize quad settings, loss reduction and ability to find new settings when a quad fails inside DTL tank.

PIP Linac Physics work has made big improvements and continues to add to previous efforts

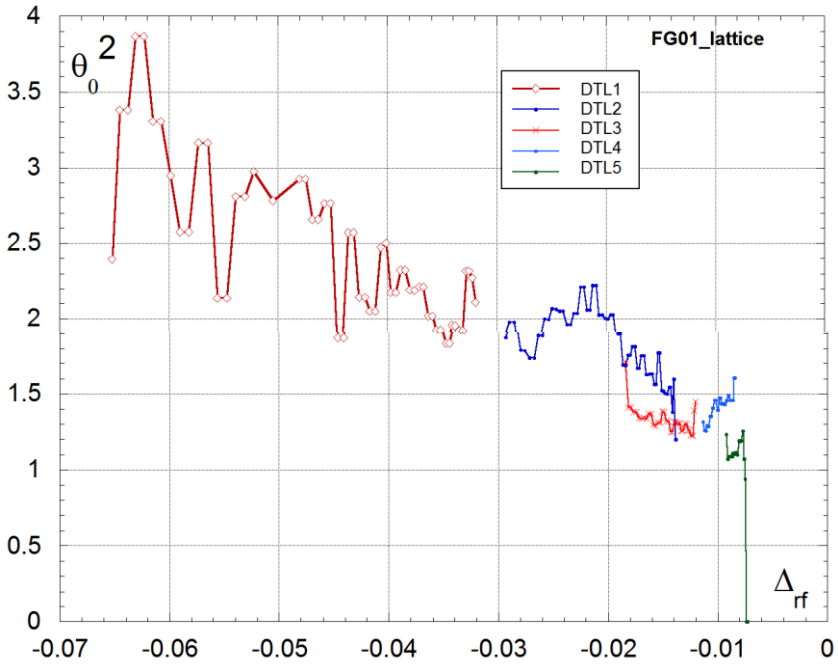
Not done – accurate model still not completed

Linac optics is difficult – DTL Tank (especially 1) issues

The task seems nearly impossible (many issues): alignment of elements, lack of diagnostics, steering issues, quad strengths & tank modeling (inter-tank).

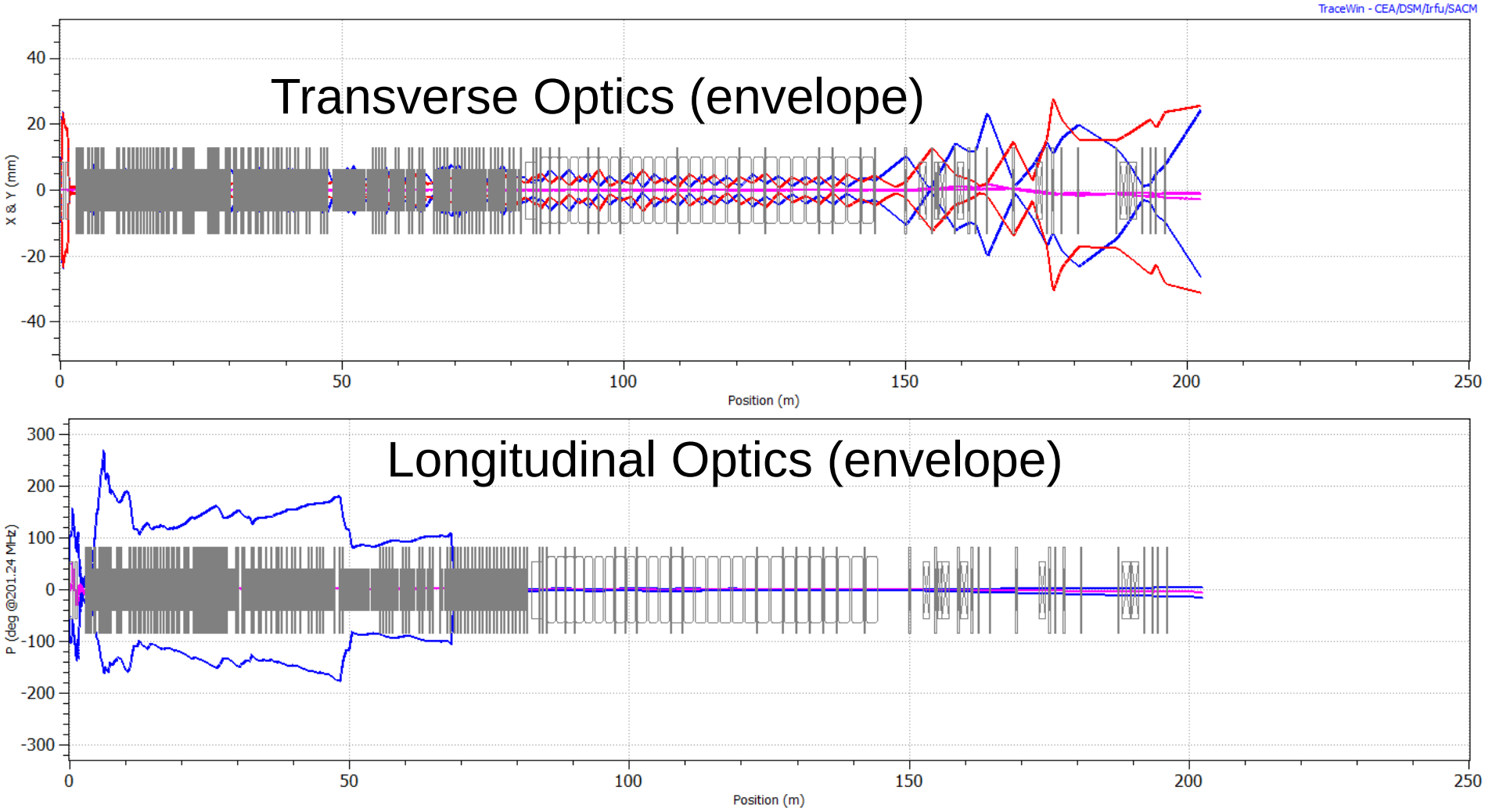


Quad strengths - stability diagrams



Envelopes along the Linac + transfer line

Work continues to try and match actual performance with design.



Linac Diagnostics BPM and Toroid upgrade completed

Crate #	Location		IP Address Decimal	IP Address Name	BPM Names Master		Slave 1		Slave 2		Slave 3		Slave 4		Slave 5	
1	Low-Energy Linac	Tank 2	131.225.131.199	LNBP01	LEL 2 Out	33										
2		Tank 3	131.225.131.205	LNBP02	LEL 3 In	19	LEL 3 Out	12								
3		Tank 4	131.225.131.207	LNBP03	LEL 4 In	14										
4		Tank 5	131.225.131.209	LNBP04	LEL 5 In	43	LEL 5 Out	57								
5	Diagnostics Room	LDR-0	131.225.131.249	LNBP05	HEL 0-2	23	HEL 0-3	54	HEL 0-4	30	HEL 1-1	39	HEL 1-2	21	HEL 1-3	13
6		LDR-0	131.225.131.218	LNBP06	HEL 2-1	31	HEL 2-2	34	HEL 2-3	48	HEL 3-1	59	HEL 3-2	44	BP201	27
7		LDR-0	131.225.131.242	LNBP07	HEL 3-4	28	HEL 4-1	53	HEL 4-2	45	HEL 4-3	52	HEL 4-4	56	HEL-3-3	17
8		LDR-1	131.225.131.243	LNBP08	HEL 5-1	22	HEL 5-2	60	HEL 5-3	49	HEL 5-4	35	HEL 6-1	29	HEL 6-2	2
9		LDR-1	131.225.131.248	LNBP09	HEL 6-3	40	HEL 6-4	6	HEL 7-1	58	HEL 7-2	26	HEL 7-3	36	HEL 7-4	55
10	400 MeV Line	LG1-RR2-3	131.225.138.107	MTABP7	BP204	38	BP203	5	BP202	25	??	16				
11		LG1-RR4-1	131.225.138.108	MTABP8	Q1	15	Q2	10	LAM	41	Q3	89	Q4	63	Q5	70
12		GR24-RR6-1	131.225.138.109	MTABP9	Q6	73	Q7	71	Q8	68	Q9	51				
13		GR24-RR6-3	131.225.138.110	MTABP10	Q10	90	V-Q11	11	Q12	18	DEB	42	Q13	24		
14		GR24-RR6-3	131.225.138.111	MTABP11	Q15	3	Q16	69	Q14	8	Q17	92	SEPU	86	HSEPD	
15		GR24-RR6-3	131.225.138.025	MTABP12	PFOIL	9	L1D	67	S01	64	L1U	66	S24	72		

15 Crates – over 60 BPMs

The new digital BPM system is commissioned:

ACNET and Java applications

Hardware/Diagnostics software

Provide average Position, Intensity, & Relative Phase over each beam pulse for every BPM @15Hz

Modulators – From tube based to solid state

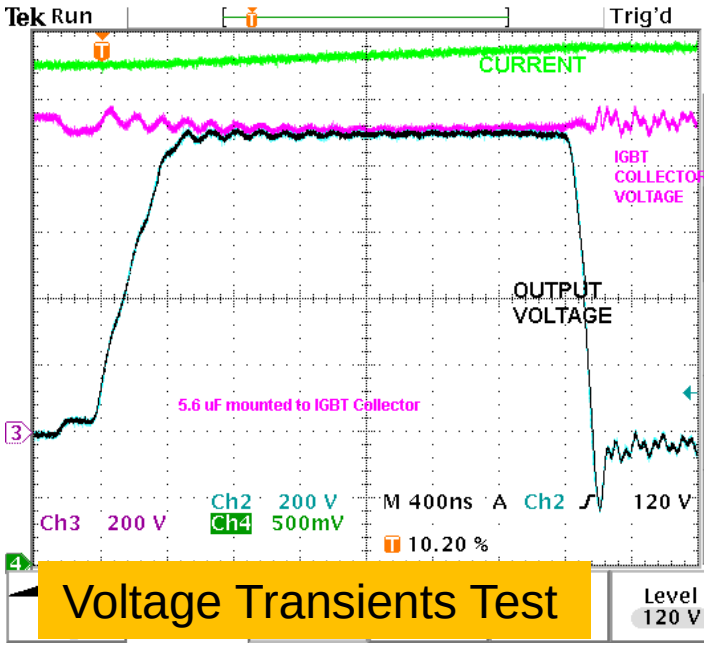
The Linac DTL 7835 tube modulator is ~45 years old and is increasing difficult to maintain. Rebuild and replace (old or obsolete parts) was considered but a fully modern system was decided.

Designs being considered:

In house IGBT (EE/PS dept)

SLAC – Marx generator

Testing Underway - Future Talk



Voltage Transients Test

IGBT

IGBT, Snubber, and Main Storage Capacitor

9-cell construction

Linac 200 MHz Power Systems
7835 triode

The high power RF 7835 tube is a Linac vulnerability with reliability issues. This has been a concern for many years for FNAL and other laboratories. After considering several options which looked at cost, labor, schedules and risk, a plan was developed and approved by laboratory management.

1. The buildup of a 4 year 7835 inventory
2. To design and build a new solid state modulator (keep 7835)
3. Replace tube systems in driver with Solid State when possible
4. Investigate 7835 replacement
    1. Investigate LANL option
    2. Investigate Klystron option
        1. Budget and plan for prototype with eventual system option

Linac High Power

Present

7835

7835 socket

The purchase of a 200 MHz Klystron has just been completed. The device will arrive in FY15 and then tested. This will be the first of its kind and will need to be fully tested before proceeding.

Some key specs:

5 MW Single Beam Klystron

450μs pulse

~19 feet

(F. Garcia, A. Moretti led effort – scheduled talk)

Linac Utilities

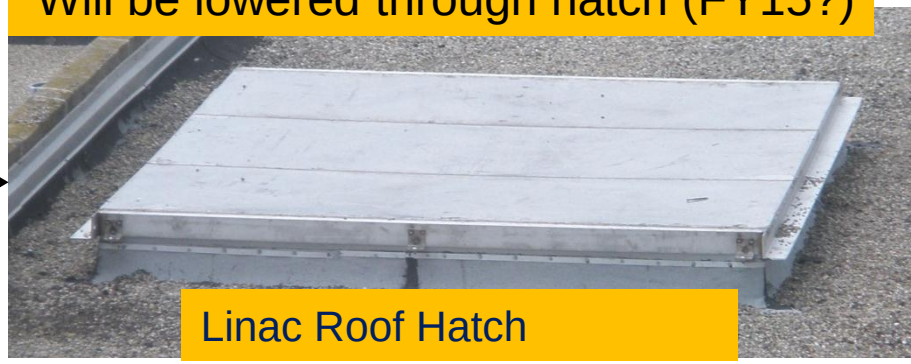
The Linac power distribution system is under powered, has obsolete parts and is largely buried in the Linac lower gallery – new system will replace only part of present system.

Critical vacuum systems update such as the LE roughing stations – along with flanges and valves.

Updated Roughing Pumps

Substation Enclosure >18,000 lbs

Will be lowered through hatch (FY15?)

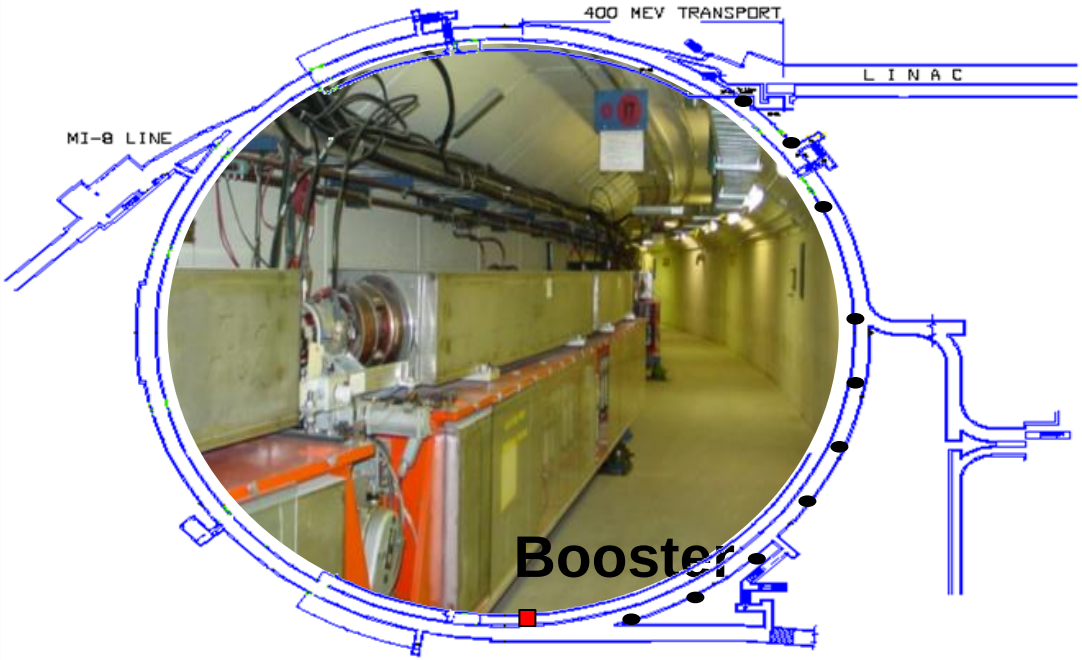


Linac Roof Hatch

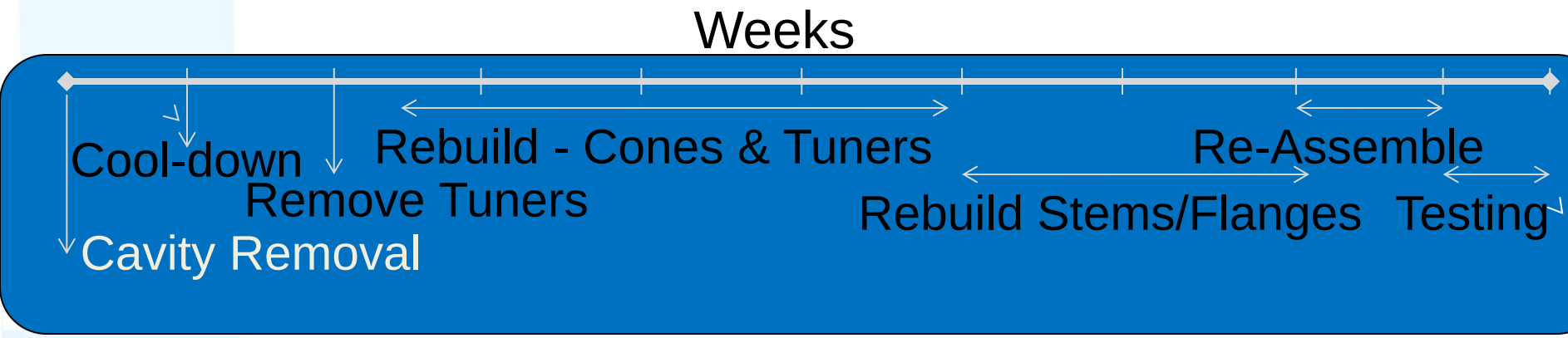
Booster PIP

- 15 Hz operation
  - RF cavity refurbishment
  - Bias Supplies
  - Anode Supplies
- Flux
  - Beam Physics
    - Optics and Alignment
    - Cogging
  - Notch System
  - Collimation
  - RF Harmonic
  - Dampers
  - Shielding
- Reliability
  - RF Solid State
  - Low Level Upgrades
  - RF Cavities and tuners
  - Utilities (LCW, Power Systems, Vacuum)
  - BPMs

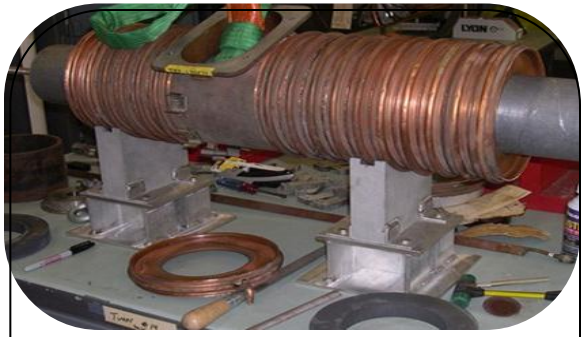
Many tasks have multiple benefits - Reliability, Flux, 15Hz operation but also skills and accelerator technology



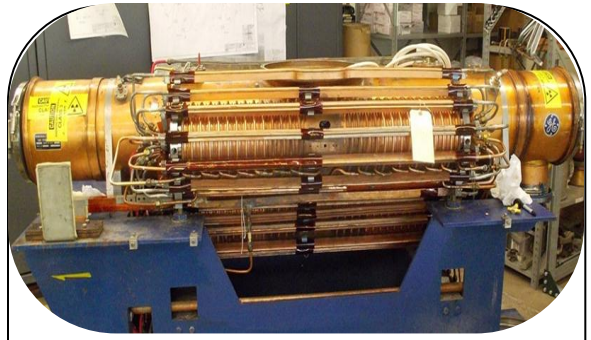
Booster PIP - Refurbishment of 40 year old cavities (facelift)



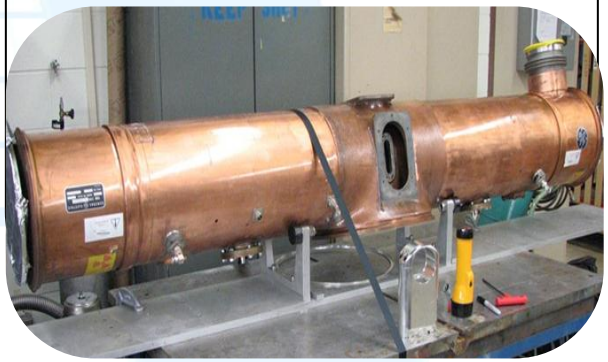
Cavity Removal - Stripping

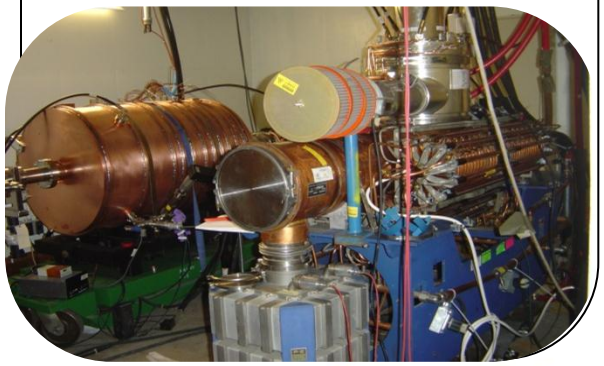


Tuners Rebuild



Rebuild and Test





Refurbishment - continued

Fun Facts

You need all cavities in tunnel to be refurbished before higher rep rate operations

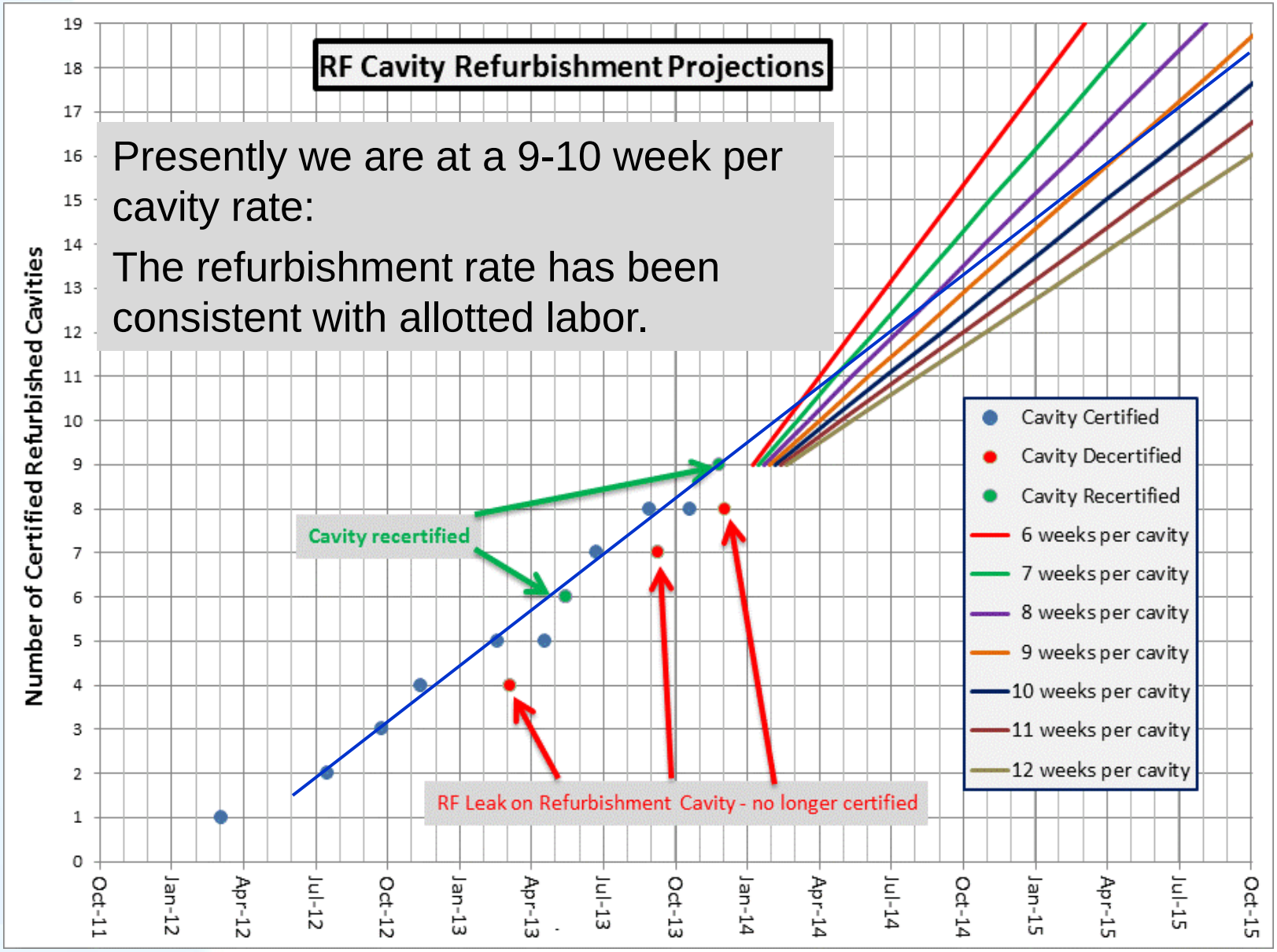
After refurbishment is completed – higher flux will require time

After refurbishment is completed – the cavities will still be OLD

There is likely to be failures as cavities are run harder

Talk at later date by Matt Slabaugh and John Reid

Booster PIP - Cavity Refurbishment Timeline



Anode Supplies and Bias Supplies (15 Hz operation)

Anode
Modern

Bias
Transformer
Heat Sinks

Refurbishment

Design is nearly complete

Install this summer both anode supplies: (EE / RF Dept.)

East gallery complete

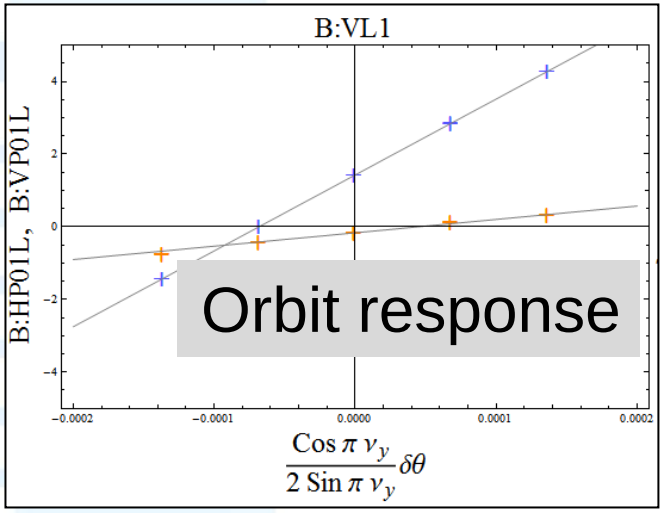
West gallery supplies work underway but slow – will be finished FY15

Completed
Power Distribution

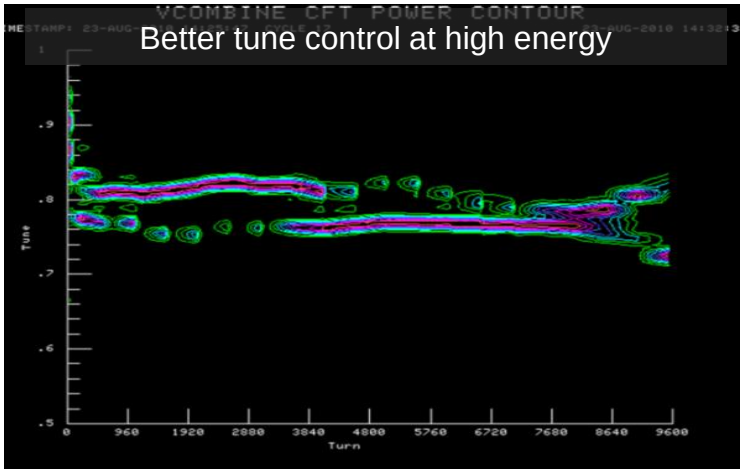
Completed
LCW

Completed
Solid State Drive System

Beam Physics – Aperture, Tunes, Beta Beating, Coupling, Chromaticity and Orbit Control



Tune Control Through Cycle

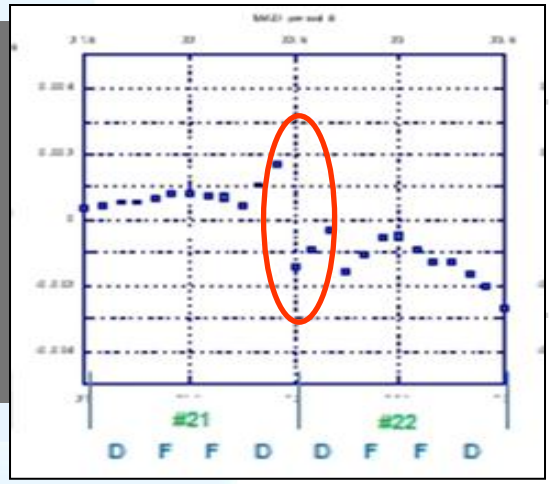


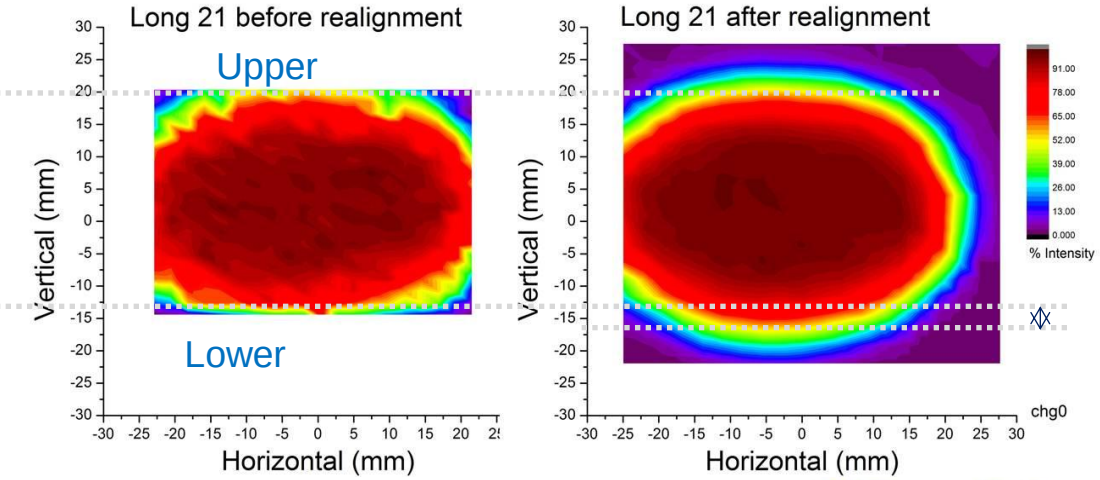
- Improve acceptance with goal of reducing beam loss
- Two magnets were realigned prior to 2012 shutdown as a bench test to verify procedure

5 mm

0

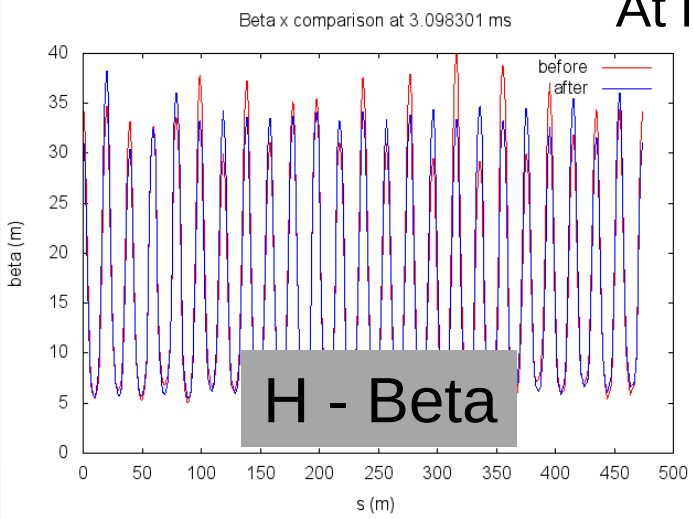
-5 mm

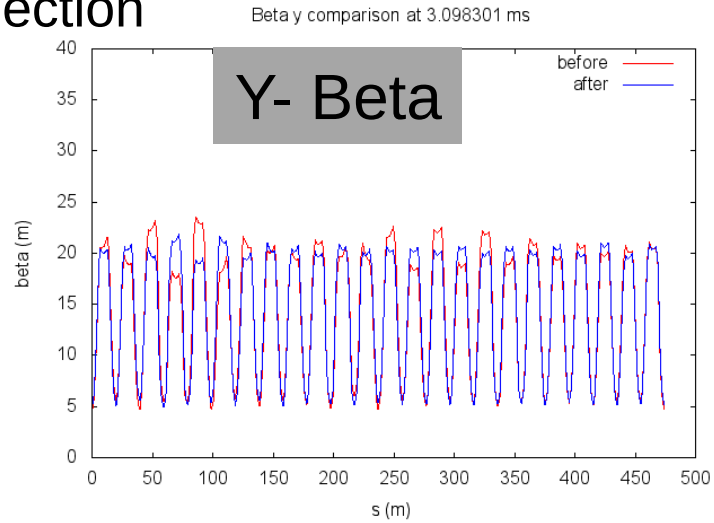




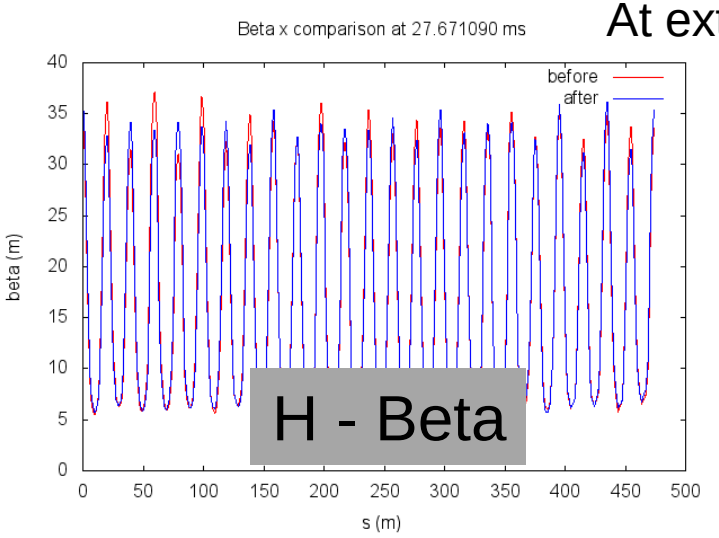
LOCO corrections – making progress on Booster Beta corrections

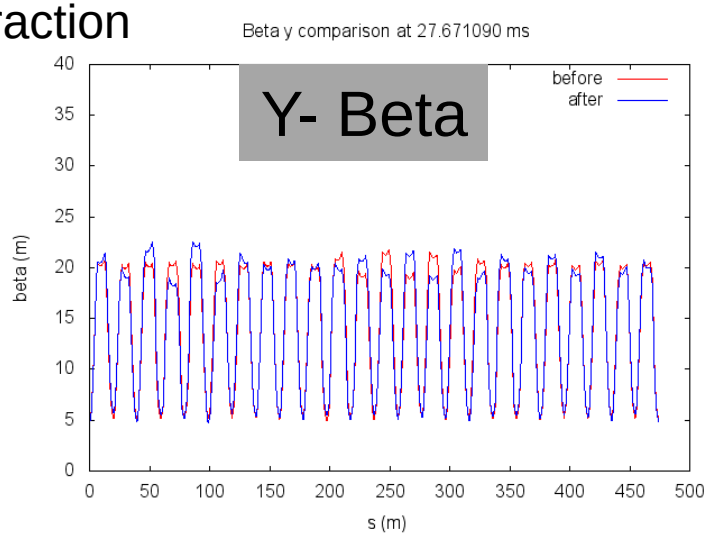
At injection





At extraction

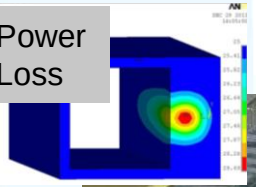




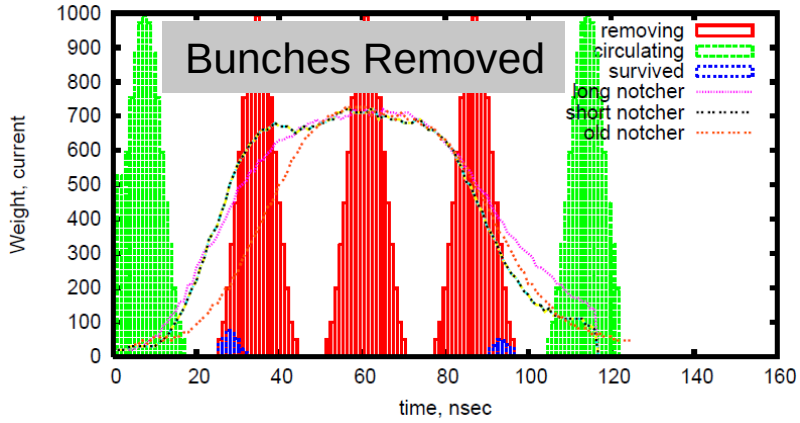
Booster PIP – Notcher & Absorber

The new absorber system is working well. Building of new PS and short kickers underway.

Power Loss



Absorber



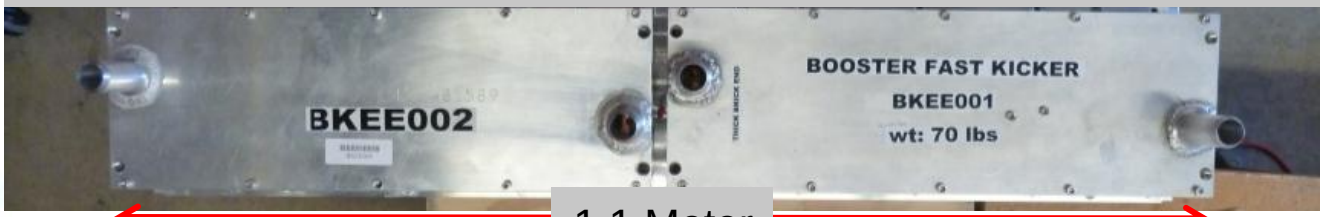
The above plot shows current notch simulation

Shorter kickers will have faster rise times, cleaner notch and reduced kick on circulating beam.

Testing complete of 4 short kickers – 2 more later

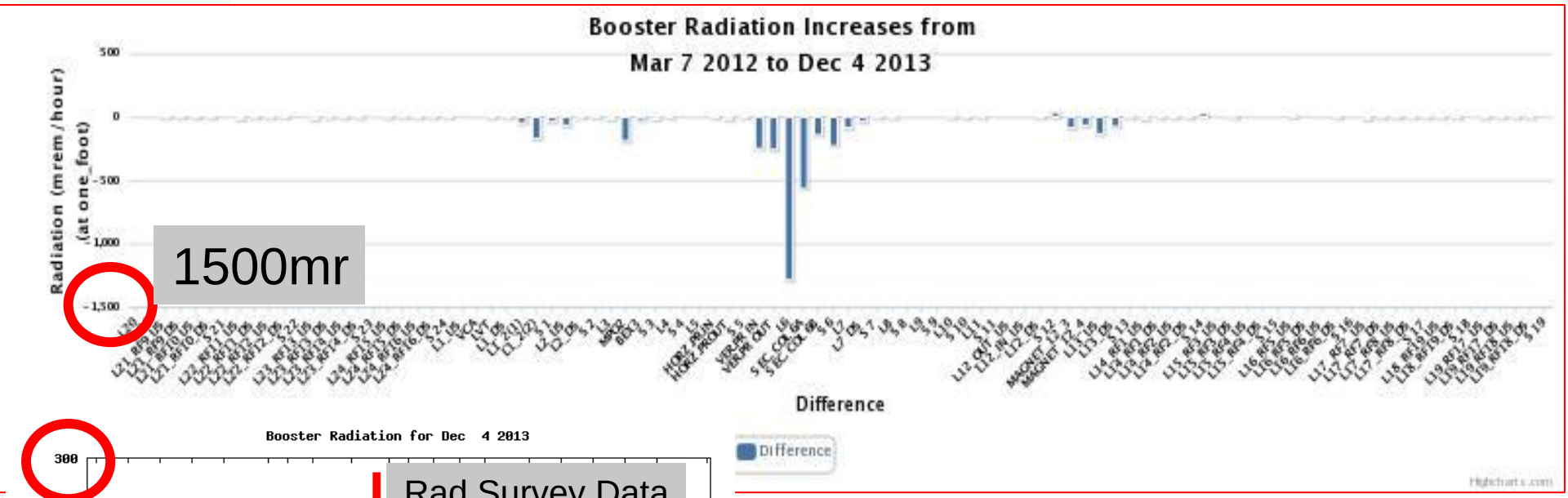
New pulser NOvA style

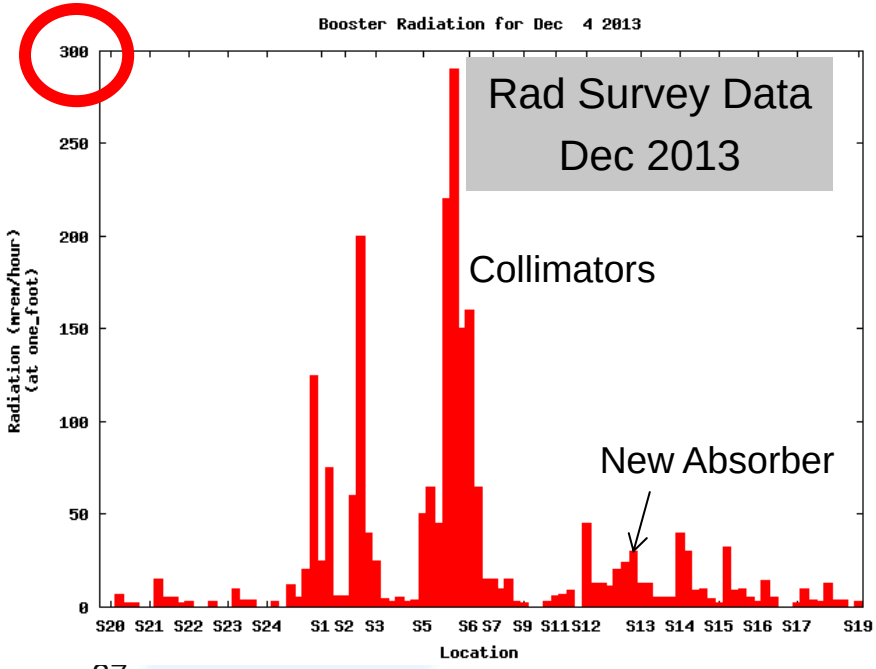
Booster Short Kickers – drop in replacements



1.1 Meter

PIP – Booster Notcher & Absorber Continued



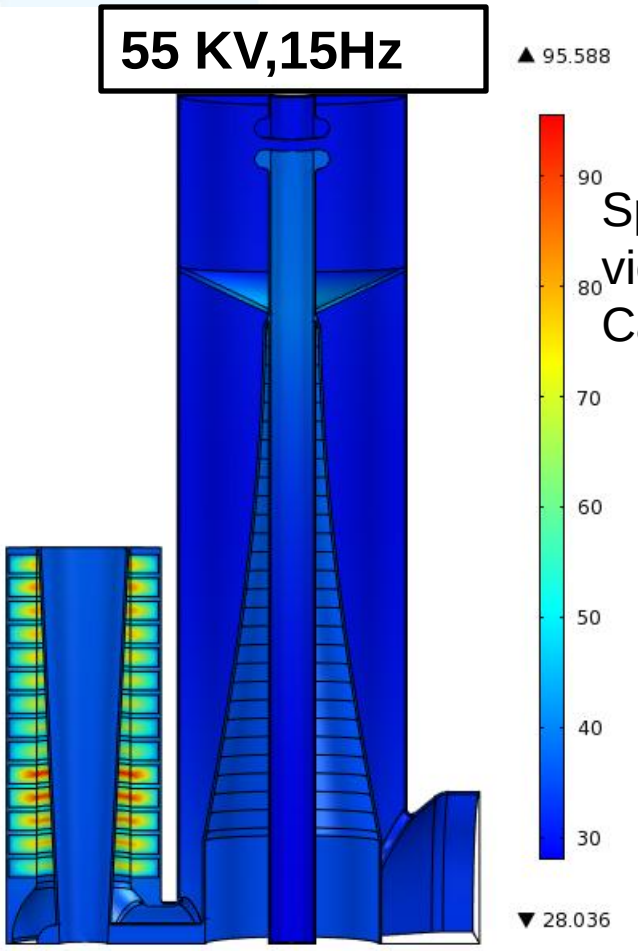


The two plots show the difference between two rad surveys after running similar flux for a week. The new system has greatly reduced residual activation in several areas of Booster.

The new absorber system directs the beam to an absorber – old system was not designed for high flux and the kicked beam 'notch' into collimators was uncontrolled

Booster PIP - New Cavities and Harmonic Cavity

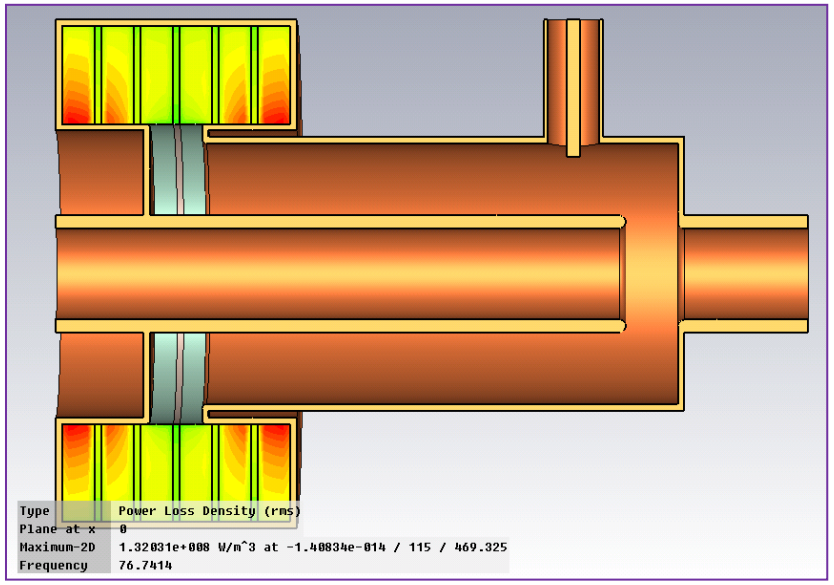
Specifications for Design of New Accelerating Cavities for the Fermilab Booster underway with testing of current cavities to confirm modeling.



Split Image view of Booster Cavity

Thermal Profile (F)

- Harmonic cavity work is underway to help with beam capture, transition and possibly extraction.
  - Based upon work at TRIUMF and LANL
  - Simulations look promising
  - University interest – Illinois Institute of Technology

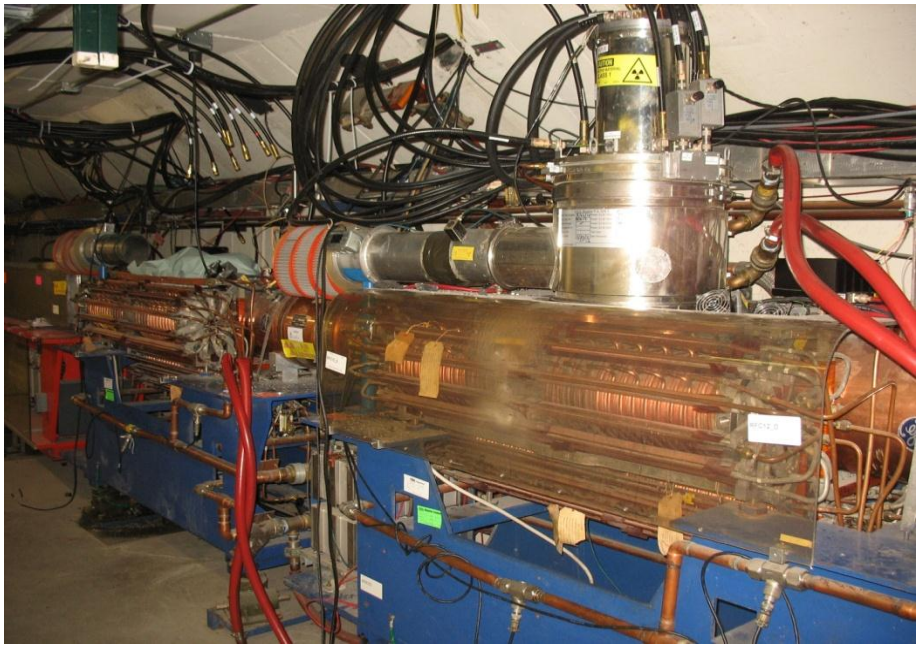


Magnetic loss density (100 kV)

PIP – Booster Solid State Upgrade Completed

With the completion of the SS upgrade, the Booster RF power system can now cycle at 15 Hz. Other expected benefits include higher uptime, lower exposure, ability to do beam loading compensation and lower operating cost by ~1M/year

Started in 2004 (1 cavity only) completed only after PIP initiated



Booster Utilities

Replacing Original Equipment

Roughing Station (1 of 4)

Vacuum:

Turbos, Roughing Stations, Ion pumps and Valves

2 Utility Substations (1000kva) Breakers & MCC

Account	M&S k$
2103.02.05.03.AD AD-Booster PIP Vacuum Systems Replacement	$403
2103.02.05.01.AD AD-Booster PIP 95 LCW Improvements	$311
2103.02.05.02.02.AD AD-Booster PIP Transformer Installation	$324
2103.02.05.02.01.AD AD-Booster PIP Transformer Acquisitions	$62

Isolation Valve

LCW: Valves, New plumbing, Pumps, Hoses, Bypasses in galleries and general repairs

Accessible Filtering

Isolation Valve

New LCW Return System

Booster Shielding

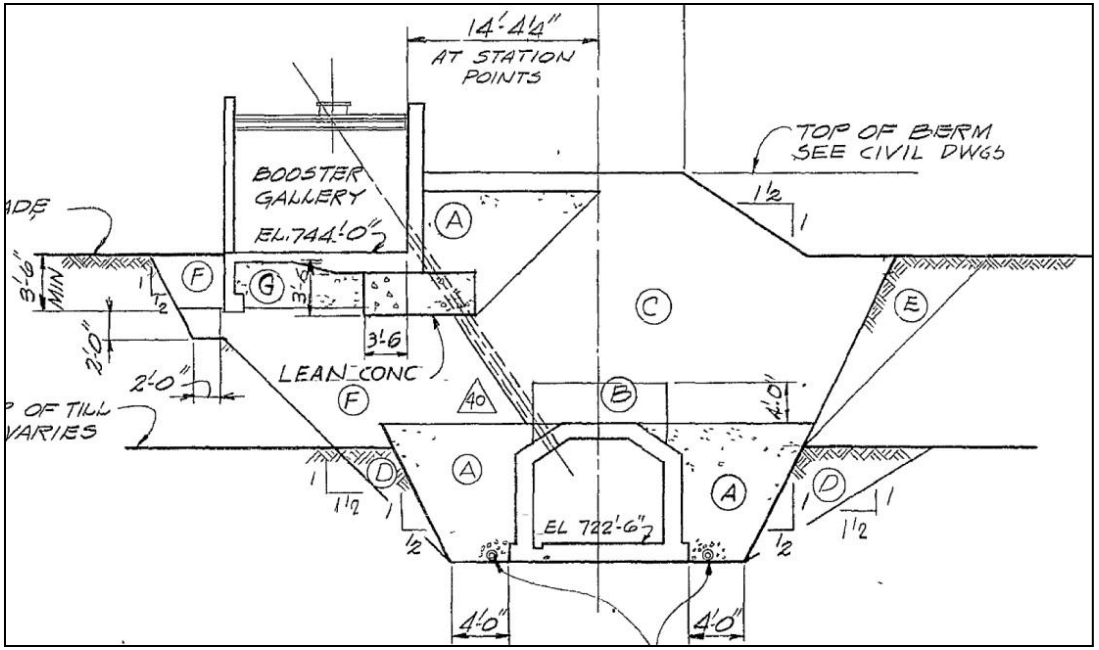
Goal – 2.7E17 p/hour

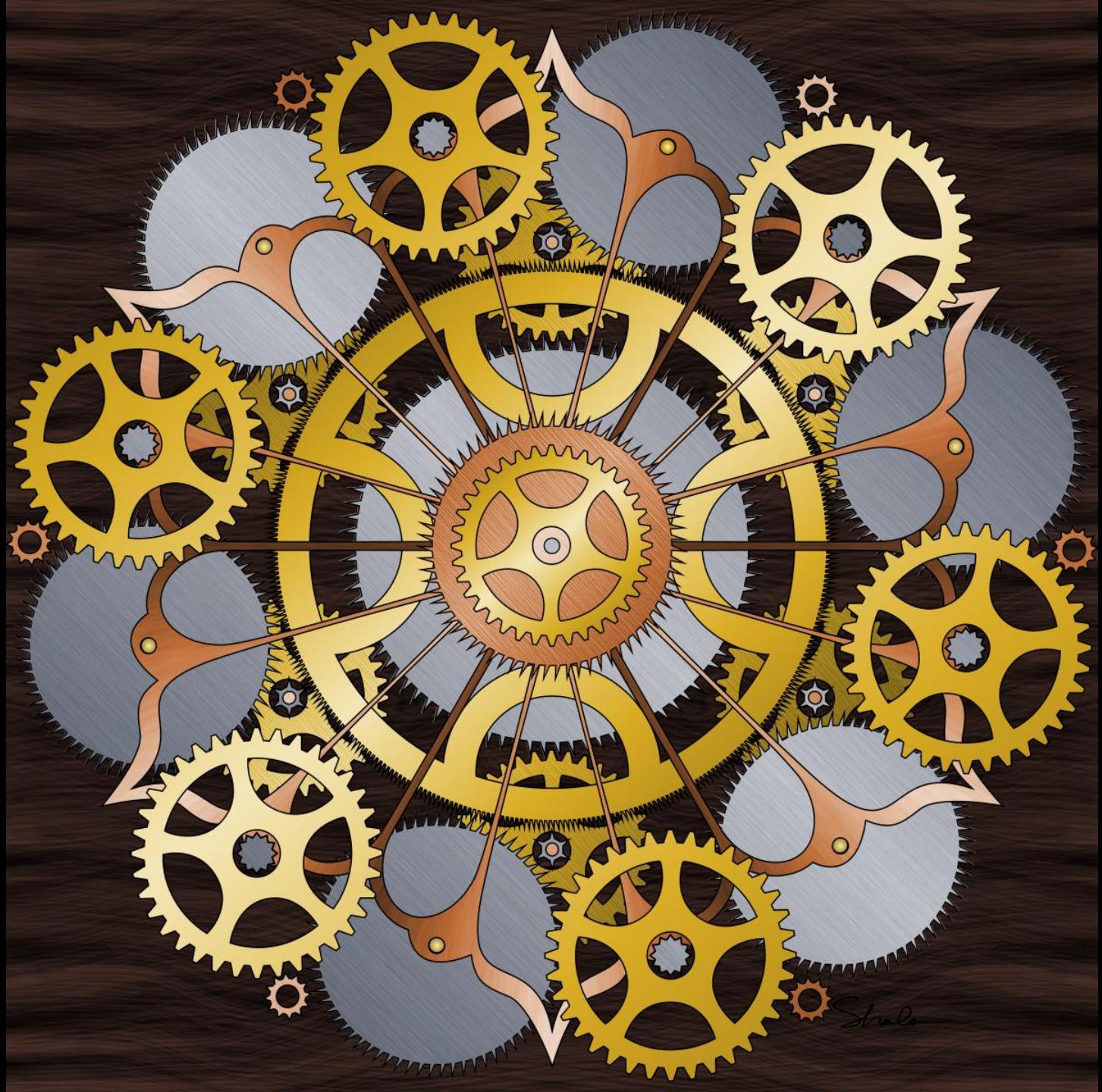
A Booster shielding assessment is underway:

- Several rounds of scans have been performed
- First round of analysis completed
- Preparing for another set of measurements – based upon earlier results

Need to finish by FY15

- Assessment Beam Parameters
- Shielding Requirements
- Longitudinal Shielding Summary
- Transverse Shielding Summary
- Labyrinths and Penetrations
- Air Activation
- Ground Water and Surface Water
- Soil Activation
- Muons
- Residual Dose Rates
- Active Shielding Controls





What is a project?

- **Angst** of what *is*, and what *is not* a "project"
  - Jargon of "project-lite"
- **DOE O 413.3b** applies to only a very narrow subset of projects
  - Large "acquisition of capital assets", or construction projects
- In general (outside of DOE-world), projects are efforts with a temporary existence and specific goals
  - **PIP is a project!** (by any conventional definition)
- So, how does PIP fit into our understanding of projects from DOE?
  - PIP is supported by operations and applies to existing machines
  - Previously, this may have been termed a campaign or program
- Regardless of the above, **PIP must implement a project management methodology to be successful, though not specifically covered by 413.3b**
- This will be an interesting (subjectively) study of how to manage a major project outside 413.3b

Managing PIP

- Developed useful processes that are familiar, though different than 413.3b
  - PIP Project Management Plan
    - c.f. Project Execution/Implementation Plans
  - PIP Design Handbook
    - c.f. CDR / TDR
  - Cost/Schedule
    - Bottoms-up RLS
  - Reporting
    - Regular reports
    - PMGs
- Had input from lab management, DOE, project

PIP Development Timetable

August 2010	Task Force Report
December 2010	Proton Source Workshop
February 2011	Proton Source Improvement Plan Proposal
August 2011	1st Proton Improvement Plan Manager Meeting
October 2011	Proton Improvement Plan FY12 M&S Uploaded
January 2012	Proton Improvement Plan Design Handbook Proton Improvement Plan Management Plan Proton Improvement Plan RLS Baselined
June 2012	1st Proton Improvement Plan Quarterly Report
August 2012	1st Proton Improvement Plan PMG

Proton Source Task Force Report

Fermi National Accelerator Laboratory

August 17, 2010

- Analyzed risks within the proton source
  - Experts considered every system for reliability and maintainability through 2025
  - Identified many vulnerabilities, assessed risk and costs of upgrades
  - http://beamdocs.fnal.gov/AD-public/DocDB/ShowDocument?docid=3660
- 15 Hz pulse items were identified at this point, but the issues of increased flux were specifically not addressed
  - Future users were still not so clear, nor how to pay for upgrades

Proton Source Workshop, Dec 2010

- Discuss reliability, longevity, 15 Hz, *and* flux for two days
  - https://beamdocs.fnal.gov/AD-private/DocDB/DisplayMeeting?conferenceid=114
  - 50 participants
  - 25 presentations
- Combined with the task force report to produce the *Proton Source Improvement Plan*
  - https://beamdocs.fnal.gov/AD-private/DocDB/ShowDocument?docid=3781
  - Initial selection of scope for what would become PIP
- PIP would eventually start that next fall (FY2012)
  - Worked out how to manage the project
  - Scope was refined, particularly for consideration of flux

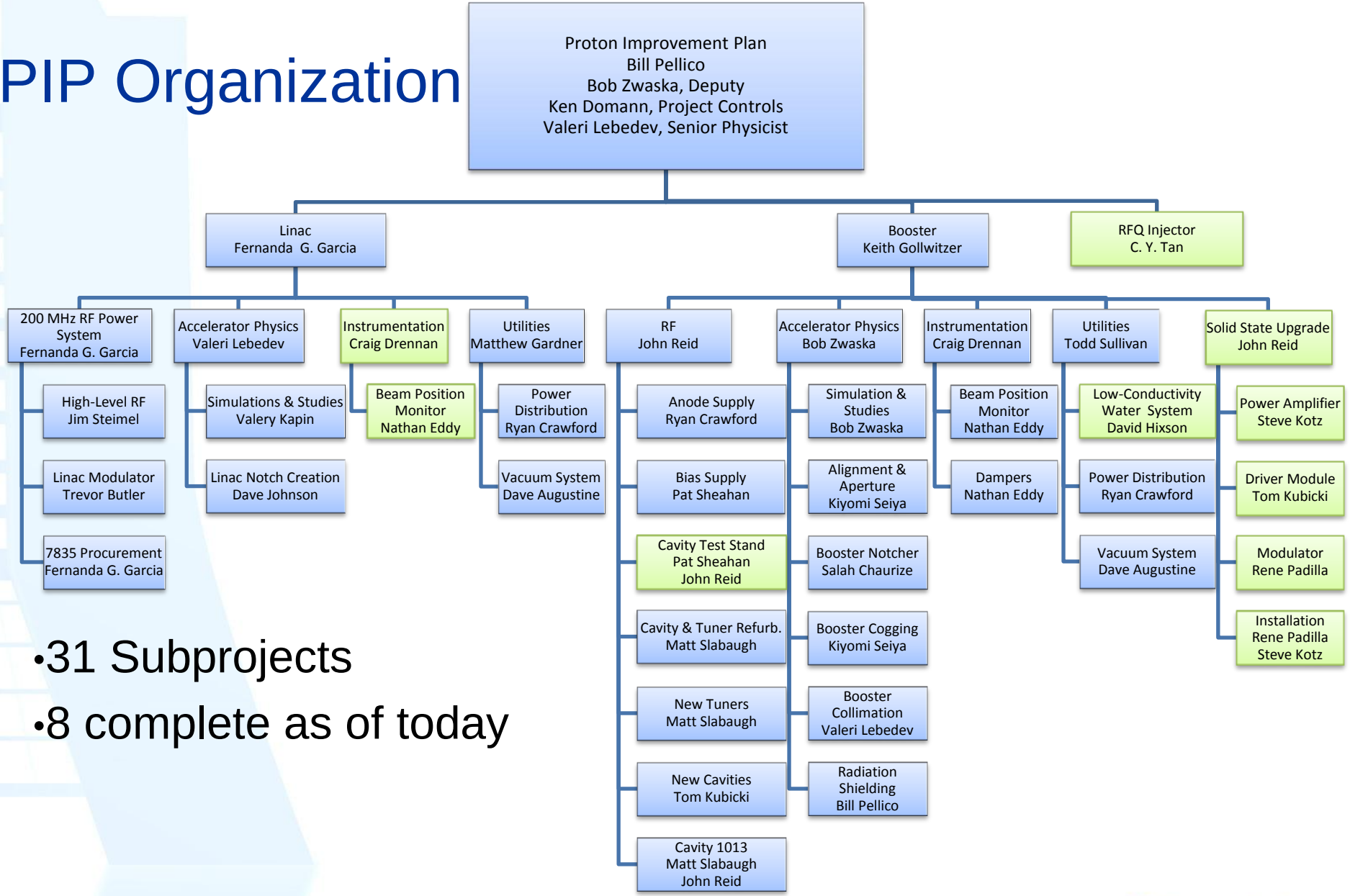
PIP Project Management Plan

- Derived from implementation and execution plans
  - https://beamdocs.fnal.gov/AD-private/DocDB/ShowDocument?docid=4052
- Spells out the basic practices for the project
- Still run the project off of this document

PIP Design Handbook

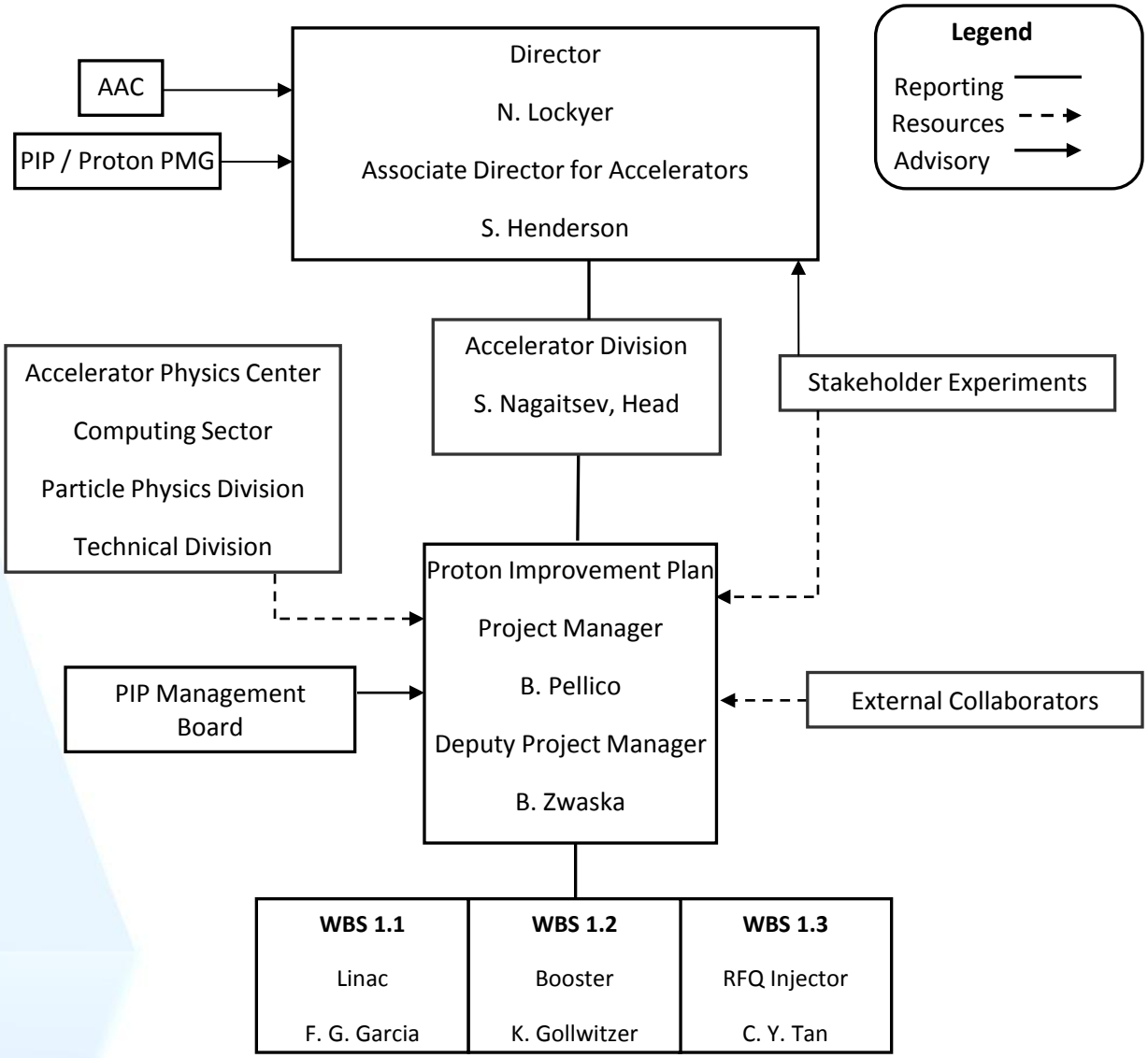
- Similar to CDR or TDR
  - https://beamdocs.fnal.gov/AD-private/DocDB/ShowDocument?docid=4053
- Has a description of scope for every item in the project and some estimates of cost and schedule

PIP Organization



- 31 Subprojects
- 8 complete as of today

Within the Larger Organization



Fermilab

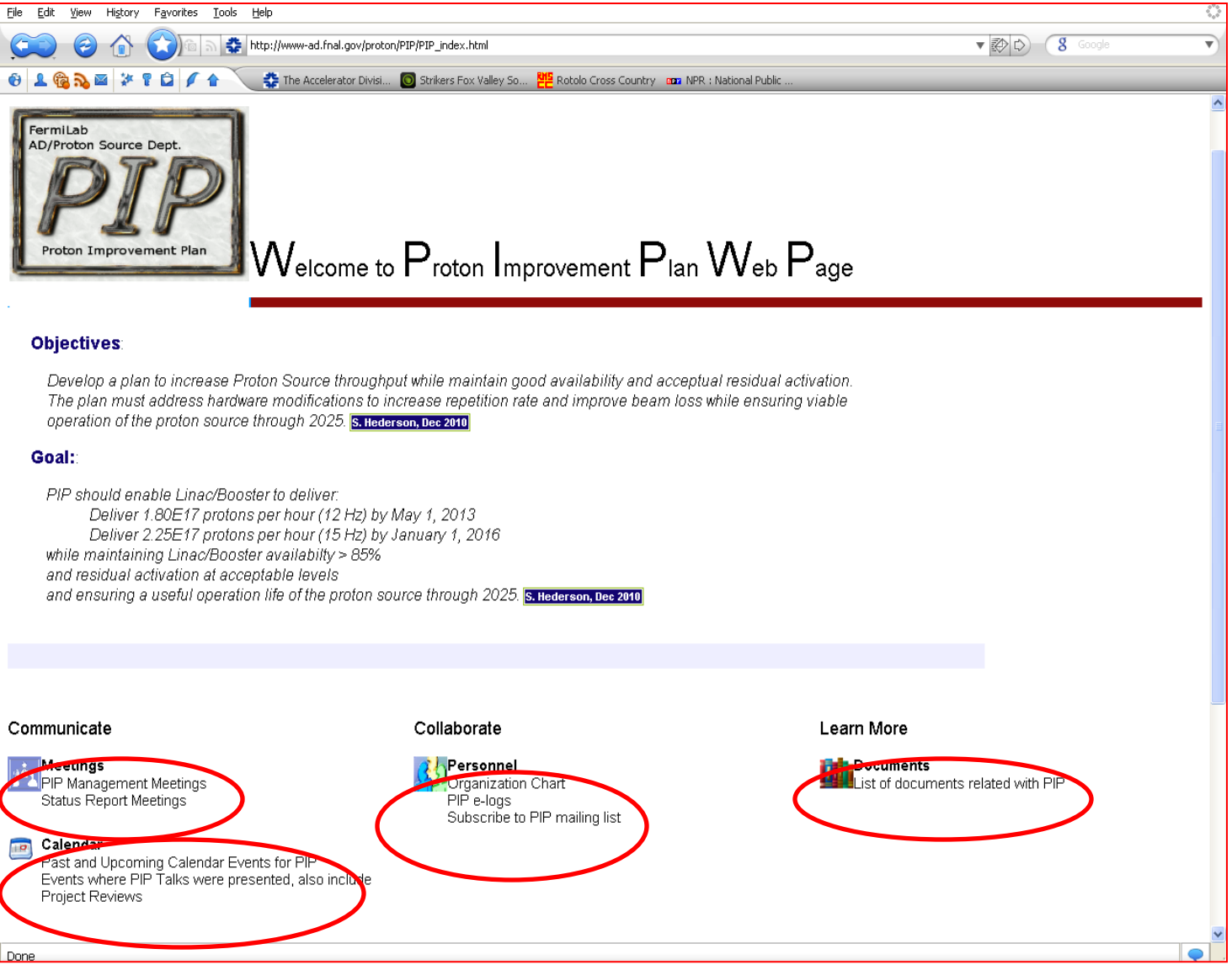
Project Management Board

- Stays in constant communication over all aspects of the process
  - Technical – financial – managerial
- Composed of project “office” & L2s
  - Pellico, Zwaska, Domann, Lebedev, Garcia, Gollwitzer
    - All part-time
    - Team approach allows us to stand in for each other
  - Previously also: Tan, Evans-Peoples, Convery (Webber)
- Small, consistent group eases flow of information

Communications

- Email lists
  - PIP: proton_improvement_plan@fnal.gov
    - Open list to anyone interested
  - PMB: pip_management_board@fnal.gov
- Regular Meetings
  - PMB meets every week “briefly”
  - General project/technical ~ biweekly
  - Specific technical ~ biweekly
  - AD management biweekly
  - Financial monthly
  - Lab PMG quarterly
- Elog
- Quarterly report submitted to lab management & DOE

PIP Documentation/Web



PIP Web Page:

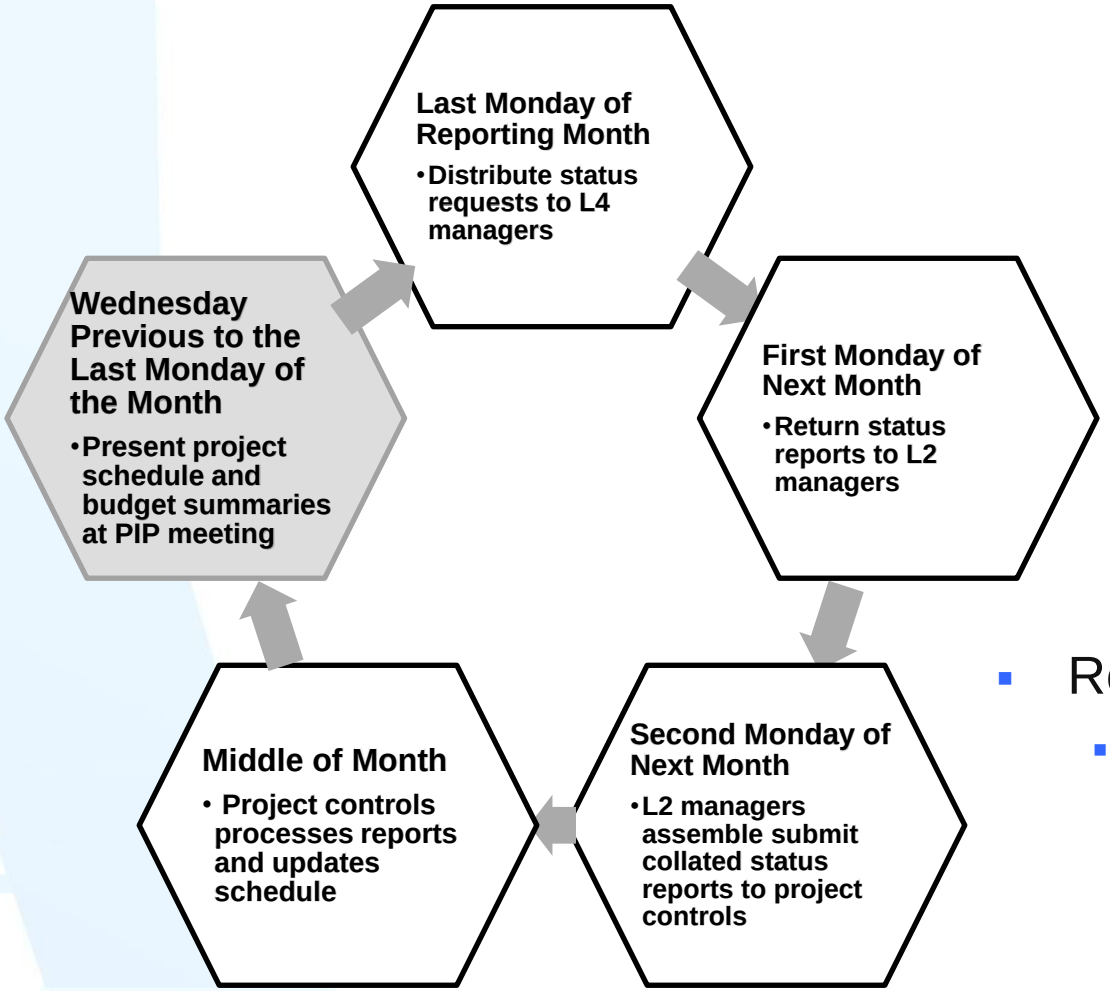
1) Meetings
   - Management
   - Task Status
2) Documents
   - Technical
   - Managerial
3) Personnel
   - Org Chart
   - Email Subscription
4) Calendar
   - Events
5) Upcoming Meeting Status

http://www-ad.fnal.gov/proton/PIP/PIP_index.html

Project Schedule - RLS

- We currently have 31 subprojects being managed
  - Most tasks have multiple charge codes
  - Every task was reviewed, baselined, fully burdened and entered into the PIP RLS
- Tasks were categorized then inputted into the RLS
    - Present RLS has 2020 lines
  - M&S
  - Labor (by name, if possible)
  - Milestones
  - Constraints (engineering, external, funding)
- Progress is reported monthly by individual tasks

RLS – Status Reporting



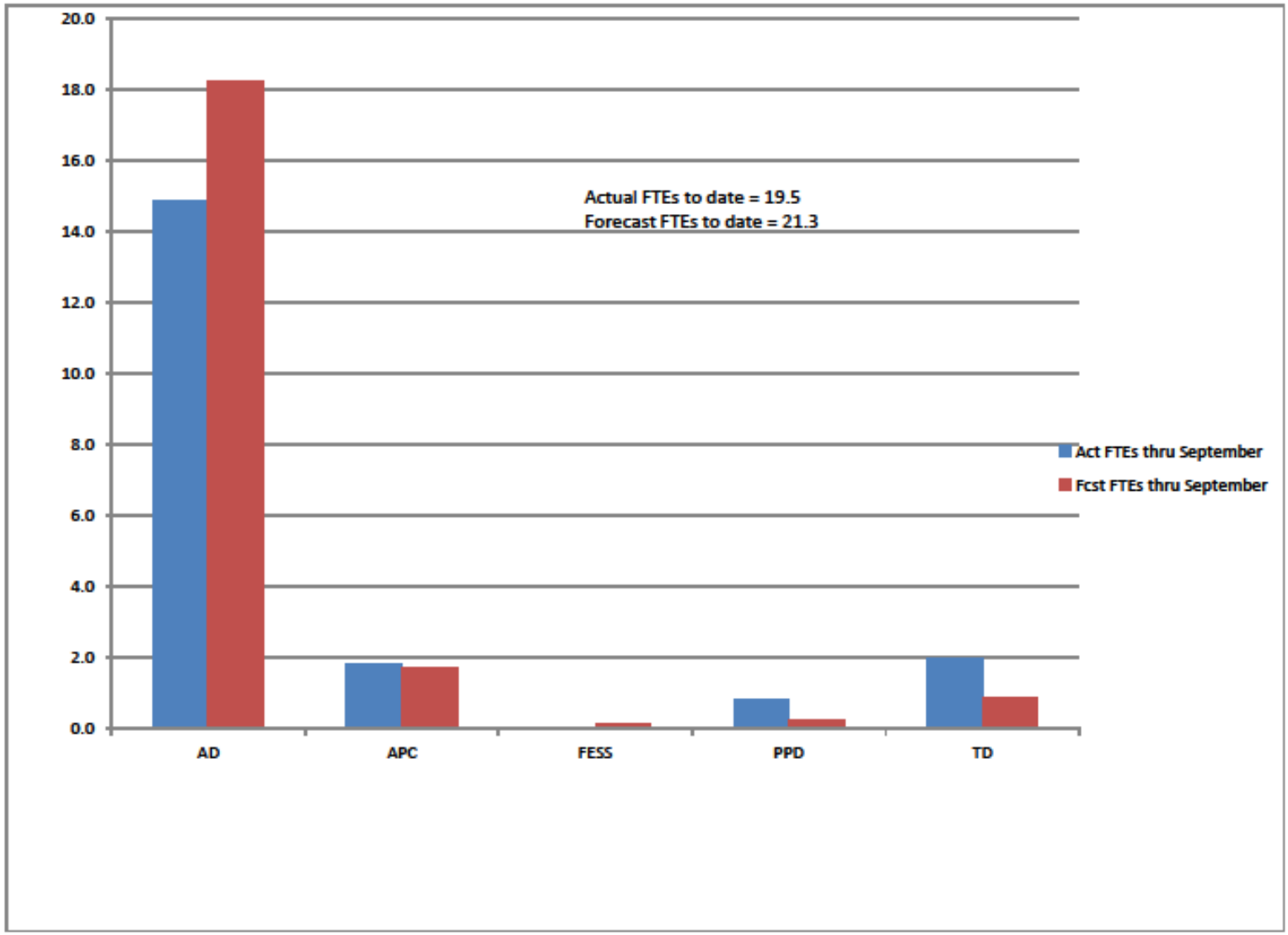
- Reporting period of 1 month
  - Balance between keeping up-to-date and overworking the system

RLS – Tracking Progress

- Budget Reports
  - Issued on a monthly basis from AD Headquarters
  - Used to load M&S and SWF actuals into RLS
  - Each month actual and status values are computed and compared to the schedule (EVMS quantities)
- Effort Reports
  - Issued on a weekly basis from AD Headquarters
  - Compare labor effort to plan and verify SWF charges (people reporting appropriately)
  - Determine FTE % to compare to labor allocations
    - Useful in discussions with departments and divisions about labor
    - Getting labor matrixed in to the project is often complicated and/or difficult
- All reported at a monthly project-wide meeting

Example

PIP Labor usage in FY2013



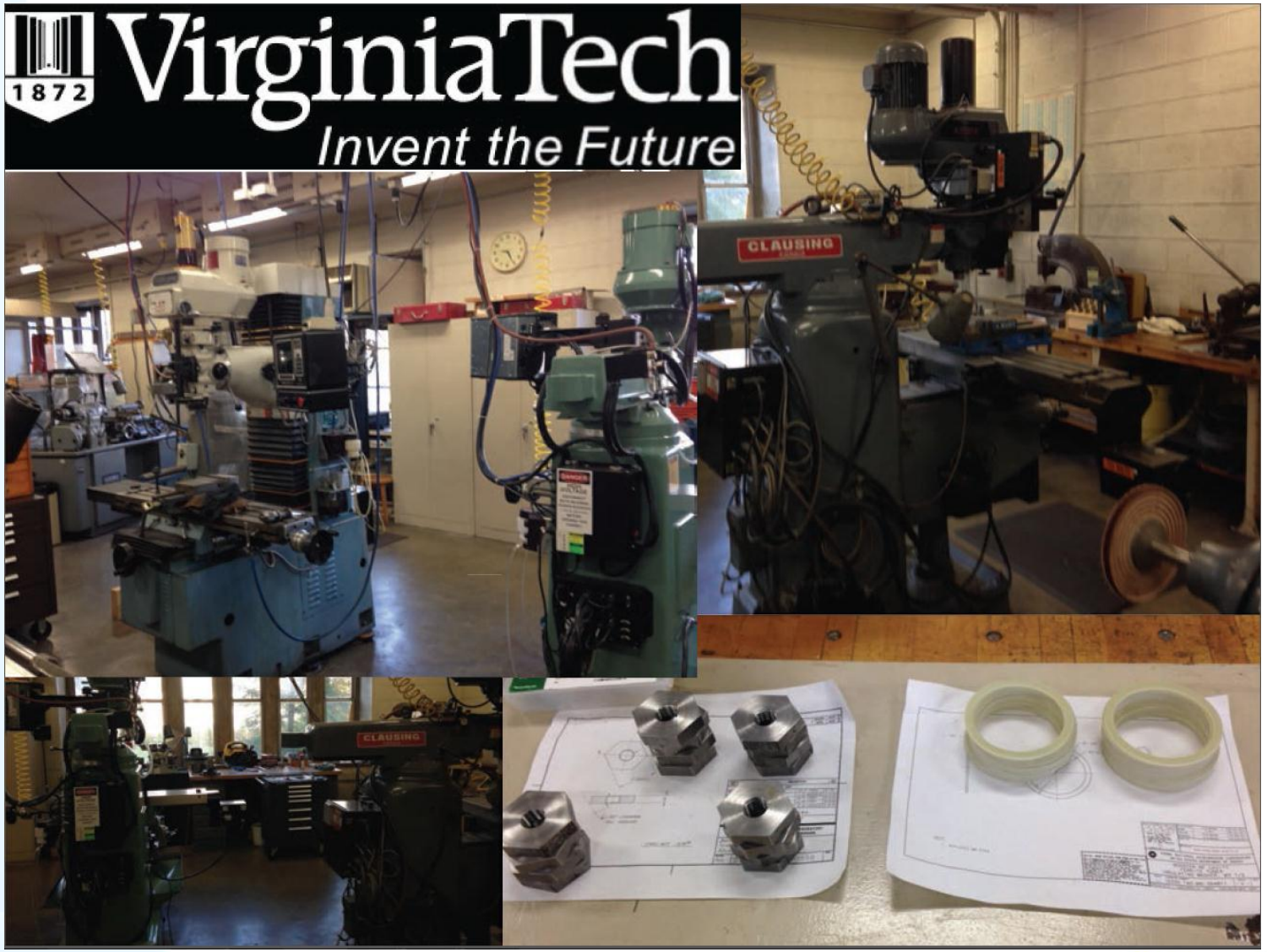
Budgeting

- A great difficulty for PIP has been how to account for budget and how the funding profile is managed
- Budget methodology:
  - PIP (with lab & DOE guidance) was initially budgeted with direct M&S and FTE counts
    - Note: division budgets are in direct dollars
  - Next iteration was with burdened M&S and FTE counts
  - Finally, we settled on a TPC-like number of burdened M&S and SWF
- Funding profile further complicated
  - Translation between budget types was not obvious
  - Profile changes several times a year
    - We have to adjust schedule continuously
  - What was initially a 5-yr project now appears to be 7 or 8
- Financial support provided through the AD division office
  - Meet on a regular basis and take part in all divisional and lab-wide budgeting exercises
  - Budget authority list established for different level managers

Reviews

- Various scales of technical reviews applied to efforts
  - Major items get specific reviews with external panels
    - For example: RFQ, L13 Absorber, klystron, cavities, …
  - Numerous internal reviews of subprojects
    - At specific or project-wide meetings
  - Individual items are subject to engineering reviews, usually within their departments
- Schedule and budget reviews held periodically within the project, usually by the PMB
  - RLS was recently completely updated – review is pending

Collaboration



William Pellico, Bob Zwaska, Feb 4, 2014

Fermilab

Conclusion

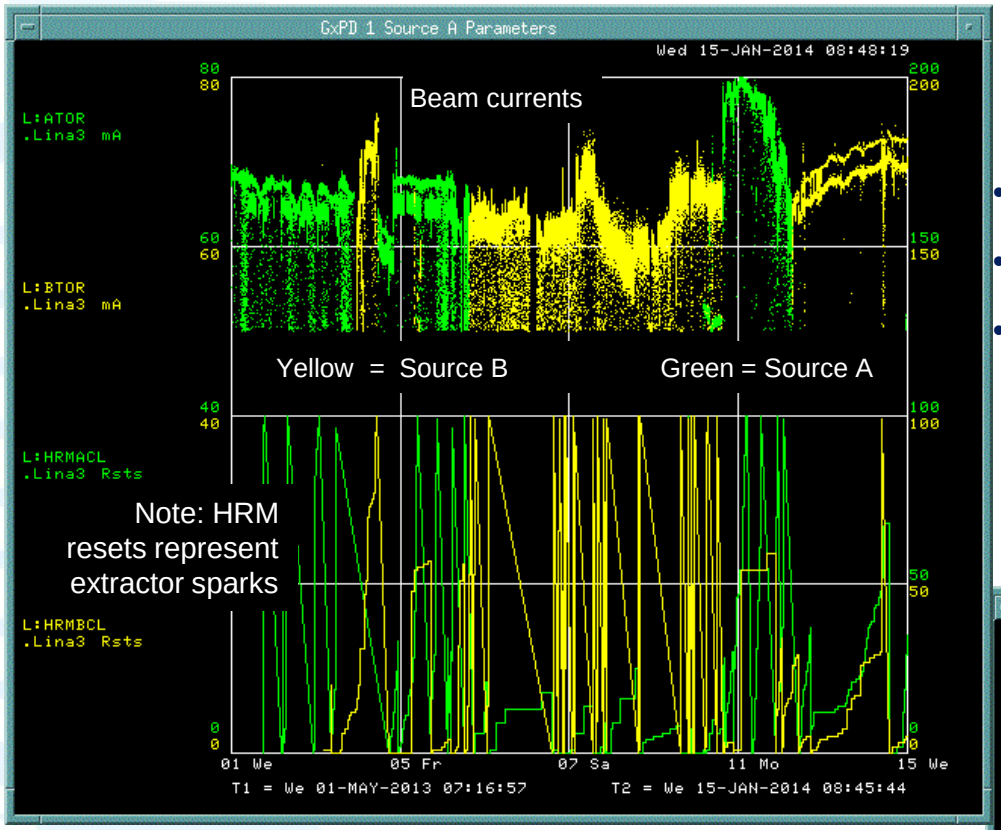
- PIP has been proceeding since it's startup in FY12
  - Project structure built to suit
  - Issues with funding have required flexibility and delays in the final PIP completion date
- Several technical achievements already complete in the project
  - RFQ, Solid-State, Notch Absorber, Utilities
- Laboratory prioritization will continue to be the determining factor in what PIP does and completion dates
  - New Cavities
  - Klystrons
  - Linac Modulators

Upcoming PIP talks

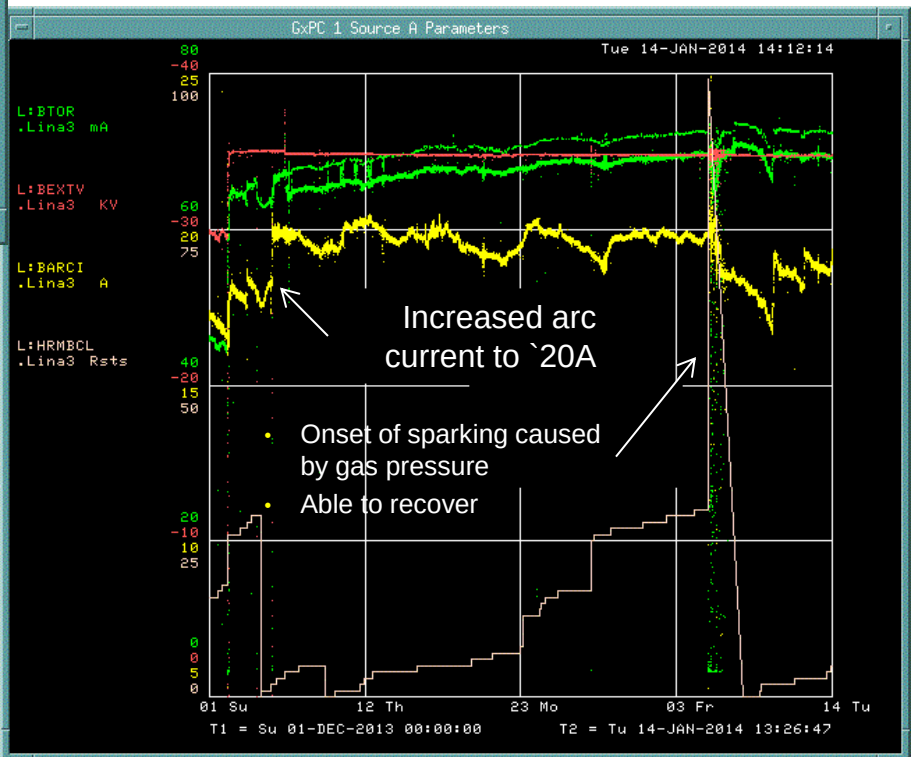
Date	Speaker	Title
03/25/2014	CY Tan, Fermilab	TBA
03/04/2014	Matt Slabaugh & John Reid Fermilab	TBA
02/25/2014	Linda Valerio, Ryan Schultz & Joe DeMarco Fermilab	Laser Welded Beam Tube: Testing & Application
02/18/2014 ** LOCATION: Curia II **	Trevor Butler & Fernanda G. Garcia Fermilab	TBA
02/11/2014	Dave Johnson, Fermilab	Linac Laser Notcher Project in the Proton Improvement Plan
02/06/2014 ** DATE: Thursday LOCATION: Curia II **	Dan Bollinger, Fermilab	35 Years of H^- Ions at Fermilab 03/25/2014

Xtra Slides

RFQ Injector Line

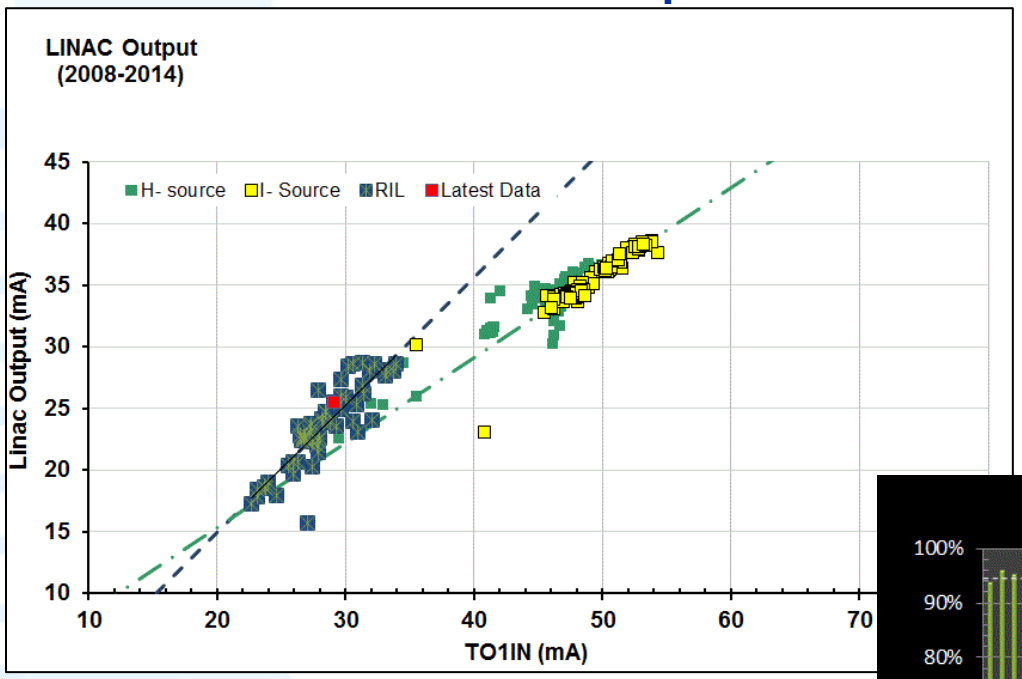


- Operations since last May
- Shows that we have used both sources
- Lots of extractor sparking initially

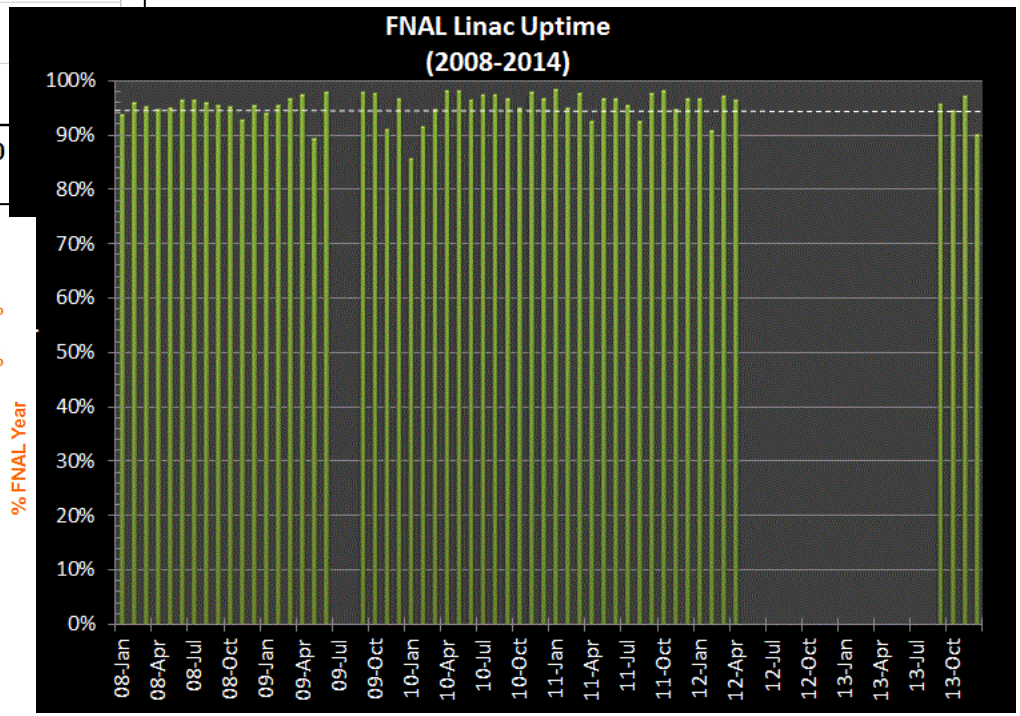


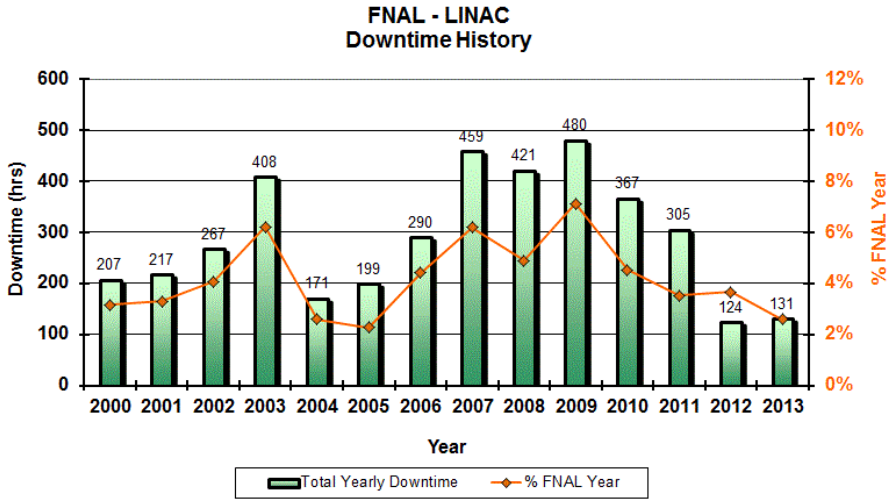
- Source B running well for 40 days with very little sparking < 2 sparks a day.
- Higher arc current, cathode and body temps
- Lower gas pressure **William Pellico, Bob Zw**

Linac Beam Operations



Linac efficiency is higher with new source but we are/will be running at lower currents (RFQ design)





Dual Temp System

Booster
02/04/2014

Linac
08/13/2011